DEC 15 1943

JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

(ACI PROCEEDINGS Vol. 40)

Vol. 15 November 1943 No. 2

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A part of PROCEEDINGS OF THE AMERICAN CONCRETE INSTITUTE Vol. 40

JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

Vol. 15 No. 2 7400 SECOND BOULEVARD, DETROIT 2, MICHIGAN November 1943

Proposed Recommended Practice for the Design of Concrete Mixes*

REPORTED BY ACI COMMITTEE 613

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INTRODUCTION

1. General comments

The design of concrete mixes is the determination of the most economical and practicable combination of available aggregates, cement, water, and, in some cases, admixture, that will produce a mixture, having the required degree of workability, and which will develop required qualities on hardening.

The most practical procedure for determining the final proportions of concrete for a given purpose is actual trial and adjustment on the job. The problem thus becomes a matter of selecting a trial mix, for starting concrete operations, that will require the least adjustment on the job.

The design of trial mixes can be accomplished most effectively by laboratory investigation of the concrete-making properties of the particular materials to be used. For work of considerable magnitude, for unusual conditions or materials, or where strength (especially flexural

*This report revised Oct. 12, 1943 was received by the Institute Oct. 18 and released by the Standards Committee for presentation to the 40th Annual ACI Convention on a motion for adoption as an ACI Standard. The report is essentially the same as the "Proposed Recommended Practice for the Design of Concrete Mixes," published ACI JOURNAL, Jan. 1942 (with discussion June 1942); *Proceedings* V. 38, p. 193, with the addition of "supplementary information," in accordance with numerous comments and suggestions by committee members and other members of the Institute. An unedited draft of the report dated September 21, received a unanimous vote of approval for promulgation as a Standard by the members of Committee 613, with the understanding that final revisions as to detail would be considered by the committee at the time of the 1944 annual meeting and offered to the Institute on the floor of the convention. The edited report, dated October 12, which embodied suggestions by most of the Committee members without altering the form and substance of the original draft, was submitted for publication without reballot by the members of Committee 613 because of insufficient time.

strength) is a controlling factor, such laboratory tests are particularly desirable. The minimum laboratory determinations that will permit effective trial mix design are tests of the grading, specific gravity, absorption, and total moisture content of the aggregates. The specific gravity of the cement may be taken as 3.15, without appreciable sacrifice in accuracy. Methods for determining these properties are prescribed in section 10.

Important factors which should be determined by tests of concrete mixes in the laboratory include:

(a) Relation between water-cement ratio and strength (compressive or flexural).

(b) Variations in workability characteristics for various combinations of the ingredient materials.

(c) Unit water contents and cement requirements for various aggregate gradings.

In addition to supplying data for more precise design of trial mixes, the laboratory tests provide information that is useful in adjusting concrete mixes in the field and for determining the relative costs of concretes made with different combinations of materials. The recommended procedure for making laboratory mix tests is outlined in section 10.

When it is impracticable to conduct laboratory concrete tests, trial mixes for starting concrete operations can be selected by judicious application of known basic concepts and established empirical relationships.

RECOMMENDED PROCEDURE

2. Outline of procedure

The six steps involved in the determination of a trial mix for initial field use are:

(a) Select the water-cement ratio from test data, experience, or established relationships, to meet the specified requirements for durability and strength (compressive or flexural).

(b) Select the limits of slump that will permit proper handling and consolidation of the concrete under the job conditions involved.

(c) Determine the largest size of available aggregate suitable for use under job conditions.

(d) Estimate, from test data, experience, or established relationships, the minimum percentage of sand that will provide the proper degree of workability.

(e) Estimate the amount of water per cubic yard of concrete that will be required to fulfill the conditions of steps (b), (c), and (d).

(f) Compute the trial mix proportions that conform with the factors determined in steps (a) to (e). Make such adjustments in the trial mix, on the job, as may be necessary.

TABLE 1—NET WATER-CEMENT RATIOS FOR VARIOUS TYPES OF CONSTRUCTION AND EXPOSURE CONDITIONS**

TABLE 1—NET WATER-CEMENT RATIOS FOR VARIOUS TYPES OF CONSTRUCTION AND EXPOSURE CONDITIONS**

Type or Location of Structure	Severe or Moderate Climate, Wide Range of Temperature, Rain, and Long Freezing Spells or Frequent Freezing and Thawing										Mild Climate, Rain or Semiarid Rarely Snow or Frost									
	Thin Sections				Moderate Sections				Heavy and Mass Sections		Thin Sections				Moderate Sections				Heavy and Mass Sections	
	Reinf.		Plain		Reinf.		Plain				Reinf.		Plain		Reinf.		Plain			
	By Weight	Gal./Sack	By Weight	Gal./Sack	By Weight	Gal./Sack	By Weight	Gal./Sack	By Weight	Gal./Sack	By Weight	Gal./Sack	By Weight	Gal./Sack	By Weight	Gal./Sack	By Weight	Gal./Sack	By Weight	Gal./Sack
A. At the water line in hydraulic or water-front structures or portions of such structures where complete saturation or intermittent saturation is possible, but not where the structure is continuously submerged:																				
In sea water	0.44	5	0.49	5½	0.49	5½	0.53	6	0.53	6	0.44	5	0.49	5½	0.49	5½	0.53	6	0.53	6
In fresh water	0.49	5½	0.53	6	0.53	6	0.58	6½	0.58	6½	0.49	5½	0.53	6	0.53	6	0.58	6½	0.58	6½
B. Portions of hydraulic or water-front structures some distance from the water line, but subject to frequent wetting:																				
By sea water	0.49	5½	0.53	6	0.53	6	0.53	6	0.53	6	0.49	5½	0.58	6½	0.58	6½	0.62	7	0.62	7
By fresh water	0.53	6	0.58	6½	0.58	6½	0.58	6½	0.58	6½	0.53	6	0.62	7	0.62	7	0.67	7½	0.67	7½
C. Ordinary exposed structures, buildings and portions of bridges not coming under above groups	0.53	6	0.58	6½	0.58	6½	0.62	7	0.62	7	0.53	6	0.62	7	0.62	7	0.67	7½	0.67	7½
D. Complete continuous submergence:																				
In sea water	0.53	6	0.58	6½	0.58	6½	0.62	7	0.62	7	0.53	6	0.58	6½	0.58	6½	0.62	7	0.62	7
In fresh water	0.58	6½	0.62	7	0.62	7	0.67	7½	0.67	7½	0.58	6½	0.62	7	0.62	7	0.67	7½	0.67	7½
E. Concrete deposited through water	*	*	*	*	0.49	5½	0.49	5½	0.49	5½	*	*	*	*	0.49	5½	0.49	5½	0.49	5½
F. Pavement slabs directly on ground:																				
Wearing slabs	0.49	5½	0.53	6	*	*	*	*	*	*	0.53	6	0.58	6½	*	*	*	*	*	*
Base slabs	0.58	6½	0.62	7	*	*	*	*	*	*	0.62	7	0.67	7½	*	*	*	*	*	*

G. Special case: (a) For concrete not exposed to the weather, such as interiors of buildings and portions of structures entirely below ground, no exposure hazard is involved, and the water-cement ratio should be selected on the basis of the strength and workability requirements.

*These sections not practicable for the purpose indicated.
**Adapted from Table 1 of the 1940 Joint Committee Report on Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete

3. Selection of water-cement ratio

The water-cement ratio should be chosen on the basis of (a) the required durability, and (b) the strength specified.

The maximum water-cement ratio for the type of construction and exposure conditions involved should be selected from Table 1. The water-cement ratio for the specified strength should be determined by laboratory tests, as described in section 10. When it is not practicable to make such tests, the water-cement ratio required for the specified *compressive* strength may be taken directly from Table 2, which gives a series of conservative values derived from a large number of tests with typical materials.

TABLE 2—COMPRESSIVE STRENGTH FOR VARIOUS WATER-CEMENT RATIOS*

Net Water-Cement Ratio		Probable Strength at 28 Days (Pounds per Square Inch)
By Weight	Gallons per Sack of Cement	
0.44	5	5,000
0.49	5½	4,500
0.53	6	4,000
0.58	6½	3,600
0.62	7	3,200
0.67	7½	2,800
0.71	8	2,500
0.75	8½	2,000

*Adapted from Table 2 of the 1940 Joint Committee Report on Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete. The strengths listed are based on the use of normal portland cement.

A corresponding table of values for flexural strength is not given because of the wider range in flexural strength which may be obtained with a given water-cement ratio for different materials. Where flexural strength is specified, the required water-cement ratio should be determined by laboratory tests, as previously stated.

The lower of the two water-cement ratios, (a) that required for durability as shown in Table 1, or (b) that required for the specified strength as determined by test or from Table 2, should always be used.

4. Selection of limiting slump and maximum size of aggregate

It is advisable to use the lowest slump compatible with proper placing. Table 3 gives the limiting values recommended for various types of construction.

For economic and other reasons, the maximum size of aggregate should be as large as practicable and available, but should not exceed two-thirds of the minimum clear distance between reinforcement. Recommended limits are given in Table 4.

TABLE 3—RECOMMENDED SLUMPS FOR VARIOUS TYPES OF CONSTRUCTION*

Type of Construction	Slump in Inches**	
	Maximum	Minimum
Reinforced foundation walls and footings	5	2
Plain footings, caissons, and substructure walls	4	1
Slabs, beams, and reinforced walls	6	3
Building columns	6	3
Pavements	3	2
Heavy mass construction	3	1

*Adapted from Table 4 of the 1940 Joint Committee Report on Recommended Practice and Standard Specifications for Concrete and Reinforced Concrete.
**When high-frequency vibrators are used, the values given should be reduced about one-third.

TABLE 4—MAXIMUM SIZE OF AGGREGATE RECOMMENDED FOR VARIOUS TYPES OF CONSTRUCTION

Minimum Dimension of Section (Inches)	Maximum Size of Aggregate*, in Inches, for:			
	Reinforced Walls, Beams, and Columns	Unreinforced Walls	Heavily Reinforced Slabs	Lightly Reinforced or Unreinforced Slabs
2½ - 5	½ - ¾	¾	¾ - 1	¾ - 1½
6 - 11	¾ - 1½	1½	1½	1½ - 3
12 - 29	1½ - 3	3	1½ - 3	3
30 or more	1½ - 3	6	1½ - 3	3 - 6

*Based on square openings.

5. Estimating the percentage of sand and unit water content

For a given set of materials and water-cement ratio, the unit water content (water required per cubic yard of concrete) is the most important basic factor affecting the quality of concrete. The optimum percentage of sand for a concrete mix is that quantity which will result in the lowest unit water content and also provide the required degree of workability, with an adequate margin to prevent difficulties from variations in working conditions and materials. Obviously, for a given water-cement ratio, the mix requiring the lowest water content will also require the least cement.

The optimum percentage of sand can be determined to best advantage on the job, under working conditions. However, laboratory mix tests with the materials to be used in the work will provide information permitting a close approximation to the proper proportion. The committee recognizes that there are several satisfactory methods, in addition to that described in section 10, for proportioning sand and coarse aggregate for trial concrete mixes. Where conditions or personal preference dictates,

use may be made of any of the basically sound methods described in the current literature (see bibliography).

It is recommended that the proportions for trial concrete mixes be determined on the basis of the estimated unit water requirements. When laboratory tests cannot be made, Table 5 may be employed. The values given in Table 5, which are average values for aggregate gradings within acceptable limits (section 10) were derived from a composite of data, information, and experience from many sources.

Table 5—APPROXIMATE SAND AND WATER CONTENTS PER CUBIC YARD OF CONCRETE

Based on aggregates of average grading and physical characteristics in mixes having a W/C of about 0.57 by weight or 6½ gallons per sack of cement; 3-in. slump, and natural sand having an F.M. of about 2.75.

Maximum Size of Coarse Aggregate	Rounded Coarse Aggregate			Angular Coarse Aggregate		
	Sand Per Cent of Total Aggregate by Absolute Volume	Net Water Content Per Cubic Yard		Sand Per Cent of Total Aggregate by Absolute Volume	Net Water Content Per Cubic Yard	
Inches		Pounds	Gallons		Pounds	Gallons
½	51	335	41	56	360	44
¾	46	310	37	51	335	40
1	41	300	36	46	325	39
1½	37	280	34	42	305	37
2	34	265	32	39	290	35
3	31	250	30	36	275	33
6	26	220	26	31	245	29

Adjustment of Values in Table 5 for Other Conditions

Changes in Conditions Stipulated in Table 5	Effect on Values in Table 5	
	Per Cent Sand*	Unit Water Content*
Each 0.05 increase or decrease in water-cement ratio	±1	0
Each 0.1 increase or decrease in F. M. of sand	±½	0
Each 1 in. increase or decrease in slump		±3%
Manufactured sand	+3	+15 lb.
For less workable concrete, as in pavements	−3	− 8 lb.

*(+) indicates an increase and (−) a decrease corresponding to the conditions stated in the first column.

6. Computation of trial mix

Assume a project which involves an ordinary heavily reinforced retaining wall having a minimum thickness of 8 in., and also a pavement slab. The concrete will be subjected to severe climatic exposure. The wall and slab have been designed on the basis of compressive and flexural strengths

at 28 days of 4,000 and 600 psi, respectively. A trial concrete mix is required, either to start a series of laboratory mix tests or, if laboratory tests cannot be made, to start concrete construction in the field. The concrete in the retaining wall will be consolidated by vibration, and the following information regarding the materials to be used in the work is available:

Cement—Type I, average characteristics.
Specific gravity—3.15 (assumed).

Sand—River sand, damp.
Medium fineness and grading.
Specific gravity—2.65 (saturated, surface dry).
Free moisture content—5 per cent by weight.

Coarse aggregate—Crushed stone, air-dry.
Reasonably well graded, angular.
Specific gravity—2.55 (saturated, surface dry)
Absorption of water—Negligible.

From Table 1 it is found that a water-cement ratio of 0.53 is the maximum which should be used for the type of structures and service conditions involved. Table 2 indicates that a water-cement ratio of 0.53 will provide the required compressive strength of 4,000 psi. The water-cement ratio required for the specified flexural strength of 600 psi can be established only by laboratory tests such as outlined in section (10-c). From Tables 3 and 4 it is concluded that a three-in. slump will be satisfactory and that 1½-in. maximum aggregate can be used.

On the basis of information given in Table 5 it is estimated that the percentage of sand for the trial mix should be 42 per cent, by absolute volume of the total aggregate, and that 305 pounds (about 37 gallons) of water will be required per cubic yard of concrete. (Actually the water content may be more or less than the estimated amount as determined by the amount of water required for a three-in. slump when a trial batch is mixed in the laboratory or on the job.)

$$\text{Cement content} = \frac{\text{Net water content}}{\text{water-cement ratio}}$$

$$= \frac{305}{0.53} = 575 \text{ lb. per cu. yd.}$$

$$= \frac{575}{94} = 6.12 \text{ sacks per cu. yd.}$$

$$\left(\begin{matrix}\text{Absolute volume,}\\ \text{water + cement}\end{matrix}\right) = \frac{\text{Water content}}{62.4} + \frac{\text{Cement content}}{\text{specific gravity} \times 62.4} =$$

$$\frac{305}{62.4} + \frac{575}{3.15 \times 62.4} = 7.81 \text{ cu. ft. per cu. yd. of concrete.}$$

$$\begin{pmatrix}\text{Absolute volume,}\\ \text{total aggregate}\end{pmatrix} = 27 - \begin{pmatrix}\text{absolute volume,}\\ \text{water + cement}\end{pmatrix}^{*}$$
$$= 27 - 7.81 = 19.19 \text{ cu. ft. per cu. yd. of concrete.}$$

$$\begin{pmatrix}\text{Absolute volume,}\\ \text{sand}\end{pmatrix} = \text{percent sand} \times \begin{pmatrix}\text{absolute volume,}\\ \text{total aggregate}\end{pmatrix}$$
$$= 0.42 \times 19.19 = 8.06 \text{ cu. ft. per cu. yd. of concrete.}$$

$$\begin{pmatrix}\text{Absolute volume,}\\ \text{coarse aggregate}\end{pmatrix} = \begin{pmatrix}\text{absolute volume,}\\ \text{total aggregate}\end{pmatrix} - \begin{pmatrix}\text{absolute volume,}\\ \text{sand}\end{pmatrix}$$
$$= 19.19 - 8.06 = 11.13 \text{ cu. ft. per cu. yd. of concrete.}$$

$$\begin{pmatrix}\text{sand}\\ \text{content}\end{pmatrix} = \text{absolute volume} \times \text{specific gravity} \times 62.4$$
$$= 8.06 \times 2.65 \times 62.4 = 1{,}333 \text{ lb. per cu. yd. of concrete.}$$

$$\begin{pmatrix}\text{Coarse aggregate}\\ \text{content}\end{pmatrix} = 11.13 \times 2.55 \times 62.4 = 1{,}771 \text{ lb. per cu. yd. of concrete.}$$

$$\text{Trial-mix proportions} = \frac{575}{575} : \frac{1{,}333}{575} : \frac{1{,}771}{575}$$
$$= 1 : 2.32 : 3.08, \text{ say } 1:2.3:3.1$$

This mix provides a starting point for a series of laboratory tests, such as described in section (10-c), or for field operations in constructing the retaining wall.

The equipment available on the job includes a three-sack batch mixer equipped with a water tank calibrated in gallons and also a water meter graduated in pounds, and batching scales for weighing the separated sizes of sand and coarse aggregate.

Cement is to be batched on the basis of integral sacks and the batch will contain three sacks, or 3 x 94 = 282 lb. of cement, which is a fixed quantity. The batch weights of sand and coarse aggregate for the trial mix will be:

Sand = $1{,}333 \times \frac{282}{575} = 654$ lb. (net), to which must be added the weight of the free moisture in the sand: $654 + (0.05 \times 654) = 687$ lb. damp sand.

Coarse aggregate = $1{,}771 \times \frac{282}{575} = 869$ lb.

7. Adjustment of trial mix.

A few batches of concrete are mixed on the job, and the average quantity of water added per batch for the desired three-in. slump is 13.1 gal. or 13.1 x 8.34 = 109 lb.

The free water in the sand is: $0.05 \times 654 = 33$ lb.
The net water in the mix is: $109 + 33 = 142$ lb.

The net water-cement ratio is: $\frac{142}{282} = 0.50$ by weight.

*Air voids assumed to be negligible. When the air content is appreciable, as when air entraining agents are used, a suitable allowance should be made, considering the air as an additional ingredient.

Since a water-cement ratio of 0.53 is desired (water content of $0.53 \times 282 = 150$ lb. for a three-sack batch), the batch requires less water than was estimated.

The absolute volume of the field batch = volume of water + absolute volumes of cement + sand + coarse aggregate =

$$\frac{142}{62.4} + \frac{282}{3.15 \times 62.4} + \frac{654}{2.65 \times 62.4} + \frac{869}{2.55 \times 62.4} = 13.13 \text{ cu. ft.}$$

The correct unit water content is: $142 \times \frac{27}{13.13} = 292$ lb. per cu. yd.

Using the corrected value for unit water content, as determined by the trial batches, the batch quantities for the adjusted mix having a water-cement ratio of 0.53, may be computed in the same manner as for the trial mix. This procedure should result in concrete having the desired three-in. slump because it is a recognized fact that for a given slump and aggregate grading, substantially the same unit water content is required for any water-cement ratio.*

*A short-cut method for adjusting a mix for change in water-cement ratio is illustrated in section 9.

The adjusted mix for 292 lb. of water per cubic yard and a 0.53 water-cement ratio is 1:2.46:3.27; say 1:2.5:3.3.

After the initial adjustment for water-cement ratio has been made and after stabilized operating conditions have been established, the optimum percentage of sand should be determined. This may be done by trial, noting the water requirement for each percentage of sand tried, until the lowest percentage compatible with proper workability, with a safe working margin, is established. The mix is again adjusted to maintain the correct water-cement ratio.

Rich mixes normally require less sand than lean mixes. After the optimum percentage of sand has been determined for a given mix, cement and sand may be interchanged by absolute volumes (keeping the sum of their absolute volumes the same) without affecting the water content or slump. For practical purposes a change in cement content of one sack per cubic yard of concrete will permit a change in sand percentage of about two.

Changes in consistency may be made by simply increasing or decreasing the amount of water to provide the desired slump, with appropriate adjustment to maintain the specified water-cement ratio.

The job mix should not be adjusted for minor fluctuations in water-cement ratio. A variation of ± 0.02 (by weight) to maintain a constant slump is considered normal.

SUPPLEMENTARY INFORMATION

8. Other methods for computation of trial mixes

Many charts, rules, and tables have been devised for use in concrete mix computations. These devices, which are largely timesavers, range in accuracy from that of the method described in the recommended pro-

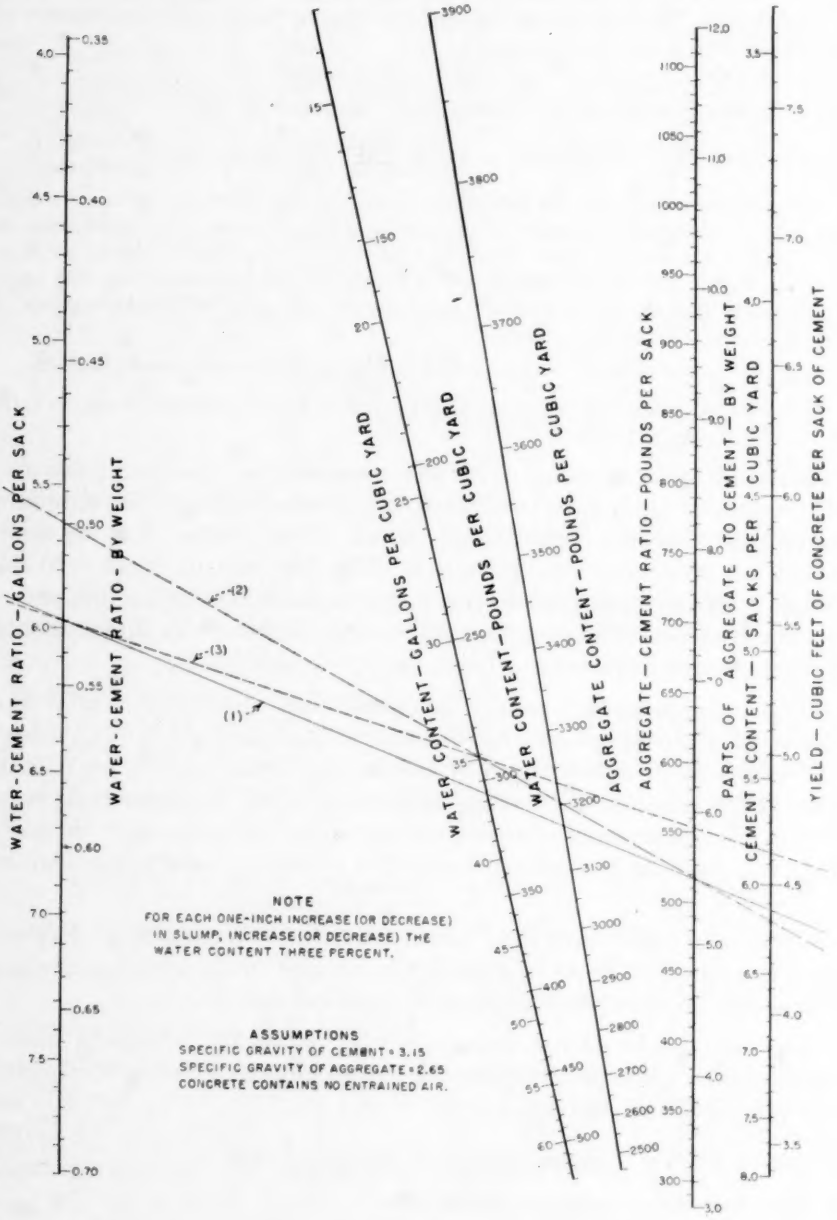
WATER-CEMENT RATIO — GALLONS PER SACK
WATER-CEMENT RATIO - BY WEIGHT
WATER CONTENT — GALLONS PER CUBIC YARD
WATER CONTENT — POUNDS PER CUBIC YARD
AGGREGATE CONTENT — POUNDS PER CUBIC YARD
AGGREGATE — CEMENT RATIO — POUNDS PER SACK
PARTS OF AGGREGATE TO CEMENT — BY WEIGHT
CEMENT CONTENT — SACKS PER CUBIC YARD
YIELD — CUBIC FEET OF CONCRETE PER SACK OF CEMENT
(1)
(2)
(3)
NOTE
FOR EACH ONE-INCH INCREASE (OR DECREASE) IN SLUMP, INCREASE (OR DECREASE) THE WATER CONTENT THREE PERCENT.
ASSUMPTIONS
SPECIFIC GRAVITY OF CEMENT = 3.15
SPECIFIC GRAVITY OF AGGREGATE = 2.65
CONCRETE CONTAINS NO ENTRAINED AIR.

Fig. 1—Chart for design and adjustment of concrete mixes

cedure to rough tables from which a mix may be chosen that may be safely used, in small work, without adjustment.

Nomographic chart—The nomograph illustrated in Fig. 1 is based on the same principles as the recommended procedure, being merely a graphic solution of these fundamentals. An explanation of the use of the chart follows—the illustration is the same as the one employed in section 6:

Water-cement ratio = 0.53 by weight.
Unit water content = 305 lb. per cu. yd.
Proportion of sand = 42 per cent.
Specific gravity: Sand = 2.65, coarse aggregate = 2.55.

Place a transparent straightedge across the nomograph—see line (1) on chart—to connect scale points for water-cement ratio of 0.53 and water content of 305.

Read off chart: Parts of aggregate by weight = 5.5 (for 2.65 sp. gr.)
Cement content = 1.53 bbl. per cu. yd. (6.12 sacks per cu. yd.)
Parts of sand by weight = 42 per cent of 5.5 = 2.3.

Parts of coarse aggregate by weight = 5.5 — 2.3 = 3.2 (for 2.65 sp. gr.) or $\frac{2.55}{2.65} \times 3.2 = 3.1$ (for 2.55 sp. gr.)

Trial mix = 1:2.3:3.1 by weight.

9. Other methods for adjustment of trial mixes

Short-cut methods for adjusting concrete mixes can be used with sufficient accuracy for most practical purposes.

(a) *The nomographic chart*—The nomographic chart illustrated in Fig. 1 can be used, either as shown or in any preferred variation. In the example which follows, the mix and required adjustment are the same as those employed in the recommended procedure.

Connect scale points on nomograph—line (2) on chart—for water-cement ratio of 0.50 and parts of aggregate of 5.5 (2.65 sp. gr.).

Read off chart: Water content = 292 lb. per cu. yd.

Connect scale points on nomograph—line (3) on chart—for water content of 292 and water-cement ratio of 0.53.

Read off chart: Parts of aggregate = 5.9 (for 2.65 sp. gr.)
Cement content = 1.46 bbl. per cu. yd. (5.84 sacks per cu. yd.)
Parts of sand = 42 per cent of 5.9 = 2.5.

Parts of coarse aggregate = 5.9 — 2.5 = 3.4 (for 2.65 sp. gr.) = $\frac{2.55}{2.65} \times 3.4 = 3.3$ (for 2.55 sp. gr.)

Adjusted mix: 1:2.5:3.3 by weight.

(b) *Rules for adjustment of mixes*—For those who prefer a procedure for adjusting mixes that is not dependent on charts, absolute volume computations or detail tabulations, the rules in Table 6 may be found useful.

TABLE 6—RULES AND INCREMENTS FOR MIX ADJUSTMENTS

(Constant Aggregate Grading and Specific Gravity)

To Change	To Hold	Corresponding Adjustments				
		Slump	W/C By Weight	Unit Water Content	Total (1) Mix Parts By Weight	Cement (2) Content Bbl. per Cu. Yd
CASE I						
W/C	Slump	Constant	Variable	Constant	Directly proportional to W/C	Inversely proportional to W/C
This adjustment amounts to replacing aggregate with cement (or vice versa) in a unit volume of concrete						
CASE II						
Slump	W/C	1-in. increase 1-in. decrease	Constant Constant	+3% −3%	−0.25 +0.25	+0.04 −0.04
This adjustment amounts to replacing aggregate with cement-and-water paste (or vice versa) in a unit volume of concrete						
CASE III						
W/C	Mix Parts	1-in. increase 1-in. decrease	+0.02 −0.02	+3% −3%	Constant Constant	−0.01 +0.01
This adjustment amounts to replacing cement and aggregate with water (or vice versa) in a unit volume of concrete						
CASE IV						
% of sand by Weight	Slump and W/C	Constant	Constant	For each change of 1 in % of sand change water content 2.5 lbs. in same direction	Variable (4)	For each change of 1 in % of sand change cement content 0.01 bbl. in same direction

(1) Total mix parts equals total parts of aggregate and cement.

(2) Approximate formula for cement content:

$$\text{Bbl. per cu. yd.} = \frac{(\text{Wt. of concrete per cu. ft.})\ 27^{(3)}}{(\text{Total mix parts} + \text{W/C})\ 376}$$

(3) The unit weight of concrete containing aggregate of 2.65 average specific gravity is approximately 148 lb. per cu. ft. for ¾-in. max aggregate; 150 lb. for 1½-in. max; 152 lb. for 3-in. max.

If the specific gravity of the combined aggregate differs materially from the average value of 2.65, the computed cement content may be corrected by adding or subtracting 0.02 for each 0.05 increase or decrease, respectively in specific gravity.

(4) For each change of 3 in the percentage of sand, change the parts of sand 0.1, and the total parts of aggregate, in the opposite direction, 0.15, 0.20, 0.25, and 0.30 for ¾, 1½, 3, and 6-in. maximum aggregate sizes, respectively.

Application of these rules to the mix adjustment illustrated in section 7, is as follows:

Mix 1:2.3:3.1 by weight; W/C = 0.50.

To adjust the W/C to 0.53, without changing the slump or percentage of sand by weight, Case I, Table 6, would apply.

The new total mix parts $= 6.4 \times \frac{0.53}{0.50} = 6.8$, or 1 part cement to 5.8 parts of aggregate.

Parts of sand $= 5.8 \times \frac{2.3}{2.3 + 3.1} = 2.5$

Parts of coarse aggregate $= 5.8 - 2.5 = 3.3$.

Adjusted mix = 1:2.5:3.3.

Other practical uses for the relationships given in Table 6 will be readily apparent to the concrete technician or engineer.

10. Laboratory Tests

As stated in the introduction, the design of trial mixes can be accomplished most effectively by laboratory investigations: *First*, to determine the basic physical properties of the materials to be used; and *second*, to establish certain fundamental relationships, including: (1) Relation between water-cement ratio and strength; (2) variations in workability characteristics for various combinations of the ingredient materials; and (3) unit water contents and cement requirements for various aggregate gradings.

The extent of the investigations desirable for any given job will depend on the size, importance, and service conditions of the structures involved. Details of the laboratory program will also vary depending on the facilities available and individual preferences.

(a) *Physical properties of cement.* The fineness and chemical composition of cement influence the workability and strength development of concrete; however, the only property of cement directly required in computations for the design of concrete mixes and batch quantities is specific gravity. The specific gravity of cement may be assumed to be 3.15 without introducing appreciable error in the mix computations, or it may be determined by test. A sack of cement weighs 94 pounds. It is, of course, desirable to assemble complete information concerning the cement to be used, including both chemical and physical properties.

The sample of cement should be obtained from the mill which will supply the job or preferably from the job itself, if time permits. The sample should contain ample quantity for the tests contemplated with a liberal margin of excess for additional tests that might be desirable. The test cement should be shipped and stored in air-tight containers or at least in moisture-proof packages.

(b) *Physical properties of aggregate*—Specific gravity, absorption, and moisture content are the essential physical properties of aggregates required in mix design computations. The weight per cubic foot and void content of the aggregate will be useful in analyzing concrete mixes.

For large or special types of work, various additional tests of aggregate materials, including petrographic analyses, chemical reactivity tests, soundness tests, abrasion tests, and tests for various deleterious substances, may be justified in connection with mix design studies, because all such tests yield information of value in judging the ultimate quality of the concrete and in selecting appropriate mix design factors.

Aggregate gradation, or particle size distribution, is a major factor controlling the unit water requirement, percentage of sand and cement content of concrete mixes for a given degree of workability. Some standard for comparing different aggregate gradings in concrete mix tests is needed to properly evaluate such factors as workability, cement and water requirements, benefits to be derived from processing or the use of admixtures, and the relative economy of alternative aggregate sources. Numerous "ideal" aggregate grading curves have been proposed but a universally accepted standard has not been developed. Experience and individual conditions and judgment must continue to play important roles in determining "acceptable aggregate gradings."

Table 7 may be useful in comparing the effects of different aggregate gradings in concrete mixes. The ranges tabulated are those which will normally be found desirable for the combinations of sand and coarse aggregate in Table 5, or any reasonable variation therefrom. However, practical considerations may require the use of aggregate gradings falling outside the desirable limits indicated in Table 7.

Variations in sand grading may be accomplished by (1) separation of the sand into two or more size fractions and recombination in suitable proportions, (2) adding or removing materials to balance the grading, or (3) reducing excess coarse material by grinding. Variations in coarse aggregate grading may be accomplished by (1) crushing excess material from coarser fractions or oversize material, (2) wasting excess materials from other fractions, or (3) a combination of these methods. Insofar as grading limitations and consideration of cement economy permit, the relative proportions of the various sizes of coarse aggregate used in the trial mixes should be governed by the natural grading of the materials. Whatever processing is done in the laboratory for the purpose of comparing mixes should be practical from the standpoint of economy and job operation.

Samples of aggregates for concrete mix tests should be representative of the source or sources selected for use in the work. The sand and coarse

aggregate should be washed, if required, and the coarse aggregate cleanly separated into the required size fractions to provide uniform control of mix proportions.

TABLE 7—PRACTICAL RANGES IN AGGREGATE GRADINGS FOR ORDINARY CONCRETE MIXES

Sieve Size	Cumulative Per Cent Retained (By Weight)						
	Sand	¾-in. Max.	1-in. Max.	1½-in. Max.	2-in. Max.	3-in. Max.	6-in. Max.
6-in.	...	...	...	...	...	...	0
3-in.	...	...	...	...	...	0	15 to 30
2-in.	...	...	...	...	0	...	...
1½-in.	...	...	...	0	...	20 to 35	40 to 55
1-in.	...	...	0	...	27 to 38	...	...
¾-in.	...	0	...	35 to 50	...	55 to 67	65 to 75
½-in.	...	...	45 to 55	...	65 to 70	...	...
⅜-in.	...	55 to 65	...	70 to 80	...	80 to 85	85 to 90
⅜-in.							
No. 4	...	100	100	100	100	100	100
No. 8	10 to 25						
No. 16	25 to 50						
No. 30	40 to 70						
No. 50	68 to 85						
No. 100	90 to 96						
Pan	100						

Note: The values in this table are not intended to be recommended specification limits for aggregate gradings.

(c) *Concrete mix tests*—The example used in section 6 of the recommended procedure requires flexural and compressive strengths at 28 days of 600 and 4,000 psi, respectively. A minimum series of concrete mix tests to establish the relationships needed for the selection of appropriate mix design factors is illustrated in Tables 8 and 9.

The trial mix, as calculated in section 6, provides a starting point for the laboratory test series. The first mix of the series proper is obtained by adjusting the trial mix to the correct water content and water-cement ratio. With the water-cement ratio held constant at 0.53, two mixes are made, one with 3 per cent less and one with 3 per cent more sand than the 42 per cent originally selected, to establish the effect of varying sand content on workability and on water and cement requirements.

Considering the workability characteristics of the concrete as revealed by the first three laboratory mixes shown in Table 8, it is decided that a sand content of 40 per cent, for a 0.53 water-cement ratio mix, will be satisfactory. Five additional mixes are then made with the water-cement ratio varying over a total range of 0.20 to establish water-cement ratio-strength relationships. For this set of mixes the percentage of sand is

TABLE 8—TYPICAL MINIMUM PROGRAM OF CONCRETE MIX TESTS

Maximum size aggregate—1½ in. Required slump approximately 3 in.

Mix No.	Actual Net W/C by Wt.	Sand % of Total Aggregate (by Abs. Volume)	Mix by Weight Based on Saturated Surface-Dry Aggregates	Unit Weight Lbs. per Cu. Ft.	Slump, In.	Unit Water Content Lbs. per Cu. Yd.	Cement Content Lbs. per Cu. Yd.	Workability			
								Rod-ability	Finish	Segre-gation	Remarks
Trial	.50	42	1:2.3:3.1	148.2	3	292	584	Good	Very good	None	Very workable, could use less sand.
1	.53	42	1:2.46:3.27	148.0	2¾	292	551	Good	Very good	None	Very workable, could use less sand.
2	.53	39	1:2.37:3.57	148.3	3¼	284	536	Good	Very good	None	Slightly undersanded
3	.53	45	1:2.54:2.98	147.9	3	300	566	Good	Sandy	None	Oversanded.
4	.43	38	1:1.79:2.81	149.0	2¾	287	667	Good	Excellent	None	Excellent mix, slightly sticky.
5	.48	39	1:2.09:3.15	148.6	3¼	287	598	Good	Excellent	None	Excellent mix
6	.53	40	1:2.40:3.47	148.2	3	287	541	Good	Very good	None	Excellent mix.
7	.58	41	1:2.72:3.77	148.0	2¾	287	495	Good	Good	None	Good mix.
8	.63	42	1:3.06:4.07	147.9	3¼	287	456	Good	Fair	None	Good mix, lacks cohesiveness

varied according to the water-cement ratio, or richness of mix, as indicated in the recommended procedure.

The strength data obtained from the concrete mix tests are given in Table 9. With such information, for the specific materials to be used on the job, it is no longer necessary to use the empirical values and relationships for average conditions as given in Tables 2 and 5 of the recommended procedure. The test data show that a water-cement ratio of 0.50 is required to provide the specified flexural strength of 600 psi and that a sand content of 39 per cent should provide a suitably workable mix for the pavement slab. A maximum water-cement ratio of 0.53, required for durability, and sand content of 40 per cent, will result in workable concrete that will develop more than the 4,000 psi compressive strength specified for the retaining wall. The trial field mixes may now be calculated as before or taken directly from Tables 8 and 9 by interpolation.

TABLE 9—STRENGTH DATA FROM CONCRETE MIX TESTS SHOWN IN TABLE 8

Average Unit Strengths at 28 Days

Mix No.	Compression psi of 3 6x12-in. Cylinders	Flexural psi of 5 6x6x21-in. Beams	Compression psi of 2 6x6x6-in. Modified Cubes
1	4,090	575	4,540
2	4,220	565	4,710
3	3,990	585	4,760
4	5,060	680	5,730
5	4,630	625	5,260
6	4,080	570	4,800
7	3,800	525	4,390
8	3,440	490	3,950

In conducting laboratory mix tests, it will seldom be found, even with experienced operators, that the desired conditions are obtained so precisely for every mix as indicated in Table 8. Some trial and error and rerun of mixes may be anticipated. Furthermore, it should not be expected that field materials, conditions, and equipment will permit an exact check of laboratory results, and adjustment of the selected trial mix on the job will probably be desirable. Closer agreement between laboratory and field results will be assured if machine mixing is employed in the laboratory, and this procedure is recommended. If laboratory mixer equipment is not available, hand mixing can be used. Similarly, any processing of materials in the laboratory should simulate as closely as practicable the corresponding treatment in the field.

The minimum series of tests illustrated in Tables 8 and 9 may be expanded as the size, cost, and special requirements of the work might warrant. Alternative aggregate sources, different sand and coarse aggregate gradings, different types or brands of cement, admixtures, mixes for various maximum sizes of aggregate, and concrete performance in durability, volume change, and thermal property tests, are some of the variable factors that may require consideration in more extensive programs.

(d) *Test methods*—In conducting laboratory tests, it is recommended that the latest issue of the following listed standards be used.

Cement

Sampling and physical testing of portland cement—ASTM Designation: C77.
Chemical analysis of portland cement—ASTM Designation: C114.
Fineness of portland cement by means of the turbidimeter—ASTM Designation: C115
Compressive strength of portland cement mortars—ASTM Designation: C109.
Autoclave expansion of portland cement—ASTM Designation: C151.

Water

Quality of water to be used in concrete—AASHO Designation: T26.

Aggregate

Abrasion of coarse aggregate—Los Angeles machine—ASTM Designation: C131.
Abrasion of rock by use of the Deval machine—ASTM Designation: D2.
Abrasion of stone and slag by use of the Deval machine—AASHO Designation: T3.
Abrasion of gravel by use of the Deval machine—ASTM Designation: D289.
Toughness of rock—ASTM Designation: D3.
Clay lumps in aggregates—ASTM Designation: C142.
Coal and lignite in sand—ASTM Designation: C123.
Percentage of shale in aggregate—AASHO Designation: T10
Organic impurities in sand—ASTM Designation: C40.
Organic impurities in sand—AASHO Designation: T21.
Material finer than No. 200 sieve—ASTM Designation: C117.
Sieve analysis of fine and coarse aggregate—ASTM Designation: C136.
Soundness—Sodium sulfate method—ASTM Designation: C88.
Soundness—Freezing and thawing method—ASTM Designation: C137.
Soundness—Freezing and thawing method—AASHO Designation: T103.
Specific gravity and absorption—Coarse aggregate—ASTM Designation: C127.
Specific gravity and absorption—Fine aggregate—ASTM Designation: C128.
Surface moisture in fine aggregate—ASTM Designation: C70.
Unit weight of aggregate—ASTM Designation: C29.
Voids in aggregate for concrete—ASTM Designation: C30.
Structural strength of fine aggregate using constant water-cement ratio mortar—ASTM Designation: C87.

Concrete

Machine mixing of concrete in laboratory—Bureau of Reclamation Concrete Manual—Designation: 28.
Sampling of fresh concrete—ASTM Designation: C172.
Consistency by slump—ASTM Designation: C143.
Consistency by flow table—ASTM Designation: C124.
Yield of concrete (includes unit weight test)—ASTM Designation: C138.
Air content of freshly mixed concrete—ASTM Designation: C173.

Making and storing compression test specimens in the field—ASTM Designation: C31.
Compressive strength—ASTM Designation: C39.
Compressive strength—Modified cube method—ASTM Designation: C116.
Flexural strength—ASTM Designation: C78.
Volume change—ASTM Designation: C157.
Absorption of concrete—AASHO Designation: T25.
Securing and testing specimens of hardened concrete from the structure—ASTM Designation: C42.
Cement content of hardened concrete—ASTM Designation: C85.

11. Mixes for small jobs

For very small jobs, involving only a few batches of concrete, where time or personnel are not available to determine mixes in accordance with the recommended procedure, the mixes in Table 10 will provide concrete that is amply strong, dense, and durable if the amount of water added at the mixer is never so large as to make the concrete sloppy. These mixes have been predetermined in conformity with the recommended procedure by assuming conditions applicable for the average small job.

TABLE 10—MIXES FOR SMALL JOBS

Maximum Size of Aggregate	Mix Designation	Mix by Weight	Approx. Sacks Cement per Cu. Yd. of Concrete	Pounds of Aggregate per 1-Sack Batch						
				Sand*	Coarse Aggregate					
					⅜-in. to ½-in.	⅜-in. to ¾-in.	½-in. to 1-in.	¾-in. to 1½-in.	1-in. to 2-in.	Total
½-in.	A	1:2.6:1.8	7.0	245	170					170
	B	1:2.5:2.0	6.9	235	190					190
	C	1:2.5:2.2	6.8	235	205					205
¾-in.	A	1:2.5:2.4	6.6	235		225				225
	B	1:2.5:2.6	6.4	235		245				245
	C	1:2.4:2.8	6.3	225		265				265
1-in.	A	1:2.5:2.6	6.4	235	100		145			245
	B	1:2.4:2.9	6.2	225	110		165			275
	C	1:2.3:3.1	6.1	215	115		175			290
1½-in.	A	1:2.5:3.1	6.0	235		170		120		290
	B	1:2.4:3.4	5.8	225		185		135		320
	C	1:2.3:3.7	5.7	215		200		145		345
2-in.	A	1:2.5:3.5	5.7	235	80		110		140	330
	B	1:2.4:3.8	5.6	225	90		120		150	360
	C	1:2.3:4.1	5.4	215	95		125		160	380

*Weights are for dry sand. If sand is damp, increase weight of sand 10 pounds for one-sack batch, and if very wet, add 20 pounds for one-sack batch.

These mixes do not apply for lightweight aggregate.

Procedure: Select the proper maximum size of aggregate and then, using mix B, add just enough water to produce a sufficiently workable consistency. If the concrete appears to be undersanded use mix A, and if it appears to be oversanded use mix C.

Three mixes are given for each maximum size of coarse aggregate. (Table 4 may be used as a guide in selecting an appropriate maximum size of aggregate). Mix B, for each size of coarse aggregate is intended for use as a starting mix. If this mix happens to be oversanded, change to mix C; if it is undersanded, change to mix A.

It should be noted that the mixes listed in the table apply where the sand is dry, or appears to be dry. If the sand is moist, or very wet, make the corrections in batch weights described in the note at the foot of the table.

The approximate cement contents in sacks per cubic yard of concrete will be helpful in estimating cement requirements for the job. These are based on concrete that has just enough water in it to permit ready working in the forms without objectionable separation. The concrete should slide off a shovel—not run off.

BIBLIOGRAPHY

Rene Feret—The early works of Rene Feret appear in a number of French publications, such as Annales des Ponts et Chausses, about 1892 to 1896. Numerous of his articles since 1892 are summed up in "Revue de l'Ingenieur," 1923; more recent ones are referred to later in this list.

"The Laws of Proportioning Concrete," by Wm. B. Fuller and Sanford E. Thompson, Trans. Am. Soc. Civil Engrs., December 1907, page 67. See also "Concrete Plain and Reinforced," by Taylor and Thompson.

"Design of Concrete Mixtures," by Duff A. Abrams, Bull. 1, Struc. Mats. Research Lab., Lewis Inst., Chicago, 1918.

"Proportioning the Materials of Mortars and Concretes by Surface Areas of Aggregates," by L. N. Edwards; *Proc.* Am. Soc. Testing Mats., 1918, V. 18, Part II, p. 235.

"Theoretical Studies on Proportioning Concrete by the Method of Surface Area of Aggregates," by R. B. Young; *Proc.* Am. Soc. Testing Mats., 1919, V. 19, p. 444.

"Proportioning of Pit-Run Gravel for Concrete," by R. W. Crum, *Proc.* Am. Soc. Testing Mats., 1919, V. 19, p. 458.

"Proposed Method of Estimating Density and Strength of Concrete and Proportioning Materials by Experimental and Analytical Consideration of Voids in Mortar and Concrete," by A. N. Talbot; *Proc.* Am. Soc. Testing Mats., 1921.

"Methods of Proportioning Concrete Materials—Screened and Unscreened Gravel," by R. W. Crum; Bull. 60, Iowa State College Engr. Exp. Station, 1921.

"The Use of Excess Sand and Pit-Run Gravel in Concrete Pavements," by R. W. Crum; *Proc.* Am. Soc. Testing Mats., 1922, Pt. II, V. 22, p. 330.

"Strength of Concrete, Its Relation to Cement, Aggregates and Water, by Talbot and Richart; Bull. 137, Univ. of Ill., Eng. Exp. Sta., 1923.

"Grading of Aggregates," by R. W. Crum, Proc. Highway Research Board, 1925. Presents review of work by Feret, Fuller, Abrams, Edwards and Talbot on design of concrete.

"Estimating Quantities of Materials for Concrete" by Stanton Walker, *National Sand and Gravel Bulletin*, September 1926, p. 5, Bulletin I, National Sand and Gravel Association, 1926. See also *National Ready Mixed Concrete Bulletin*, April 1931, on same subject.

"A Mathematical Method of Proportioning," by Joseph A. Kitts, *Concrete*, Nov. 1929, p. 33.

"Basic Principles of Concrete Making," by Franklin R. McMillan, McGraw Hill Publishing Co., 1929.

"Basic Principles of Concrete Making Coordinated," by Joseph A. Kitts, *Building and Engineering News*, Nov. 22, 1930.

"The Proportioning of Concrete for Strength, Durability and Impermeability," by A. T. Goldbeck; *The Crushed Stone Journal*, May 1931, p. 5, Bull. 3, National Ready Mixed Concrete Association.

"New Light on the Grading of Aggregates," by C. C. Furnas and F. O. Anderegg, *Industrial and Engineering Chemistry*, Sept. 1931.

"Tests on Consistency and Strength of Concrete Having Constant Water Content," by Inge Lyse. *Proc.* Am. Soc. Testing Mats., 1932, V. 32, Part II, p. 629.

"The Mortar Voids Method of Designing Concrete Mixtures," by Mark Morris, ACI JOURNAL, Sept. 1932; *Proc.*, (1933) V. 29, p. 9.

"Design and Control of Concrete Mixes," Portland Cement Association, 6th Edition, 1934.

"Mass Concrete Tests in Large Cylinders," by R. F. Blanks and C. C. McNamara, ACI JOURNAL, Jan.-Feb., 1935; *Proc.* (1935) V. 31, p. 280.

"The Study of Quality, the Design, and Economy of Concrete," by Inge Lyse, *Jl.* Franklin Institute, May, June, and July 1936.

"On the Shape and Surface Condition of the Particles of Concrete Aggregate," by R. Feret; *Ann. de L'Inst. Tech. du Bat. et des Trav. Pub.*, V. 2, Mar.-Apr. 1937; Reviewed ACI JOURNAL, Sept.-Oct., 1937; *Proc.* (1938) V. 34, p. 84.

"New Investigation of the Form of Particles of Concrete Aggregate," by R. Feret, *Ann. de L'Inst. Tech. du Bat. et des Trav. Pub.*, V. 3, May-June 1938, p. 31. Reviewed ACI JOURNAL, Nov. 1938; *Proc.* (1939) V. 35, p. 140.

"Effect of Particle Interference in Mortars and Concretes," by C. A. G. Weymouth, *Rock Products*, Feb. 25, 1933, p. 26.

"Aggregate Grading in Relation to Concrete Mix Design," by H. N. Walsh; *Bull.* Inst. of Civil Engrs. of Ireland, V. 62, No. 6, Apr. 1936, p. 197. Reviewed ACI JOURNAL May-June, 1936, *Proc.* (1936) V. 32, p. 728.

"The Mathematics of Minimum Voids in Concrete Aggregates," by Clyde F. Atchison, *Concrete*, Oct. 1937, p. 7.

"Grading and Workability," by W. H. Glanville; ACI JOURNAL, Jan-.Feb., 1937; *Proc.* (1937) V. 33, p. 319.

"The Grading of Aggregates and Workability of Concrete," by W. H. Glanville and A. R. Collins; Dept. of Scientific and Industrial Research and Ministry of Transport, *Road Research Technical Paper No. 5*, H. M. Stationery Office, 1938.

"Determination of Size Gradation of Aggregates, and Practical Information which it Furnishes," by J. Bolomey; *La Rev. des Mat. de Cons. et de Trav. Pub.*, June 1938, p. 106. Reviewed, ACI JOURNAL, Nov. 1938, *Proc.* (1939) V. 35, p. 143.

"A Study of Fine Aggregate in Freshly Mixed Mortars and Concretes," by C. A. G. Weymouth; *Proc.* Am. Soc. Testing Mats., 1938, V. 38, Part II, p. 354.

"Designing Workable Concrete," by C. A. G. Weymouth; *Engr. News-Record*, Dec. 29, 1938, p. 818.

"How to Design Concrete Mixtures," (JPP No. 35-21); Stanton Walker, ACI JOURNAL, Jan., 1939; *Proc.* (1939) V. 35, p. 211; J. C. Pearson, ACI JOURNAL, June, 1939; *Proc.* (1939) V. 35, p. 584; *Proc.* E. N. Vidal and W. H. Price, ACI JOURNAL, Sept., 1939; *Proc.* (1940) V. 36, p. 99.

See also: "Proportioning Concrete Mixtures," by Standon Walker, J. C. Pearson, John C. Sprague, E. N. Vidal, and W. H. Price (from ACI JL.). Circular 21 National Sand and Gravel Association, Oct. 1941; also a publication of National Ready Mixed Concrete Association.

"Elements of Modern Concrete," by Charles E. Wuerpel, *Civil Engineering*, Part I, "An Approach to the Design of Concrete," Aug. 1939, p. 463; Part II, "Aggregate Selection and Concrete Mix Design," Sept. 1939, p. 539.

"Materials Required per Cubic Yard of Slag, Stone and Gravel Concrete and Cement Mortar," by Fred Hubbard, National Slag Association, Bulletin 94-13C, 1940.

"The Properties of Concrete Mixes," by Blanks, Vidal, Price, and Russell; ACI JOURNAL, Apr. 1940; *Proc.* (1940) V. 36, p. 433.

"The Design of Concrete Mixes," by Charles T. Kennedy, ACI JOURNAL, Feb. 1940; *Proc.* (1940), V. 36, p. 373.

"Revised Application of Fineness Modulus in Concrete Proportioning," by Henry L. Kennedy; ACI JOURNAL, June, 1940; *Proc.* (1940) V. 36, p. 597.

"The Application of Some of the Newer Concepts to the Design of Concrete Mixes," by W. M. Dunagan; ACI JOURNAL, June 1940; *Proc.* (1940) V. 36, p. 649.

Report of Joint Committee on Standard Specifications for Concrete and Reinforced Concrete, published by the ACI and the ASTM, June 1940, see also *Proc.* A. S. C. E., Dec. 1940 and Bull. 419 of the A. R. E. A., Sept.-Oct. 1940, p. 27.

"Designing Concrete Mixture for Pavements," by W. F. Kellermann, *Public Roads*, Sept. 1940, p. 121; *Proc.* Am. Soc. Testing Mats., 1940, V. 40, p. 1055.

"Design and Control of Concrete Paving Mixtures—Texas," by E. B. Cape; ACI JOURNAL, Feb. 1941; *Proc.* (1941) V. 37, p. 413.

"The Design and Control of Paving Concrete in Iowa," by Bert Myers; ACI JOURNAL, Apr., 1941; *Proc.* (1941) V. 37, p. 577.

"The Proportioning of Concrete Materials," by J. C. Witt; *Concrete*, May 1941, p. 33.

"Proposed Recommended Practice for the Design of Concrete Mixes," By ACI Com. 613; ACI JOURNAL, Jan. 1942; *Proc.* (1942) V. 38, p. 193.

"A Method for Proportioning Concrete for Compressive Strength, Durability and Workability," by A. T. Goldbeck and J. E. Gray, *Crushed Stone Journal*, May-June 1942. (Also published as Bulletin 11 of the National Crushed Stone Association.)

"Significance of Tests of Concrete and Concrete Aggregates," by ASTM Com. C-9; Second Edition, 1943, Am. Soc. Testing Materials.

"Chart for the Design and Adjustment of Concrete Mixes," by Howard E. Burr, ACI JOURNAL, Sept. 1943; *Proc.* V. 40, p. 53.

The foregoing report is scheduled for presentation at the 40th Annual ACI Convention (Feb. 29-Mar. 2, 1944) on a motion for adoption as an ACI Standard. Written discussion for convention consideration should be available to the ACI Secretary by Feb. 10 and the discussion period closes March 10, 1944 for publication in the ACI JOURNAL for June.

A part of PROCEEDINGS OF THE AMERICAN CONCRETE INSTITUTE Vol. 40

JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

Vol. 15 No. 6 7400 SECOND BOULEVARD, DETROIT 2, MICHIGAN June 1944

Discussion of Report of Committee 613:

Proposed Recommended Practice for the Design of Concrete Mixes*

By A. T. GOLDBECK, C. W. BRITZIUS, A. C. AVRIL, W H. THOMAN, W. H. PRICE and A. H. YEATES and W. A. CORDON

By A. T. GOLDBECK†

Sec. 1. 4th paragraph. Before "Important Factors" etc., I would insert "For extensive work". Surely all of this preliminary work need not be done for smaller jobs where aggregates come with gradations which cannot be altered economically. Besides there are variables of curing, temperature, etc., in the field that outweigh some of these theoretical considerations such as gradation. Again, these extensive tests apply to extensive and important jobs.

Sec. 2. (a) I would add—"This will vary with different cements and aggregates."

(d) Percentage of sand is an uncertain safeguard for proper workability especially in view of the effect of air inclusions, the effect of size and shape of coarse aggregate, gradation of the sand, and the particular use for the concrete. It is safer and simpler to control the dry, rodded volume of coarse aggregate in the mix. (b/b_0) This method is practicable and logical; hence, I would make (d) read—

(d) Estimate, from test data, experience, or established relationships, the maximum dry, rodded volume of coarse aggregate per unit volume of concrete that will provide the proper degree of workability. Safe values for ordinary structural concrete and for highway concrete are as follows:

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*The Committee's report (ACI JOURNAL, Nov. 1943, *Proceedings* V. 40, p. 93) had formal presentation Mar. 1, 1944 at the Institute's 40th annual convention and on a motion for adoption, subject to amendments and editorial revisions (recorded at the conclusion of the discussion in the following pages) was adopted subject to letter ballot returnable July 28, 1944) as an ACI Standard.

†Engineering Director, National Crushed Stone Association, Washington 9, D. C. This discussion, presented in advance to Committee 613, was given outline presentation at the convention.

For Structures:

TABLE A—DRY, RODDED VOLUME OF COARSE AGGREGATE PER UNIT VOLUME OF CONCRETE (b/b_o)*

Size of coarse aggregate, square opening laboratory sieves	Fine sand		Medium sand			Coarse sand		
	Fineness modulus of sand							
	2.40	2.50	2.60	2.70	2.80	2.90	3.00	3.10
	Values for b/b_o							
No. 4 to ¾ in.	.71	.70	.69	.68	.67	.66	.65	.64
No. 4 to 1 in.	.72	.71	.70	.69	.68	.67	.66	.65
No. 4 to 1½ in.	.74	.73	.72	.71	.70	.69	.68	.67
No. 4 to 2 in.	.76	.75	.74	.73	.72	.71	.70	.69
No. 4 to 2½ in.	.78	.77	.76	.75	.74	.73	.72	.71

* b/b_o = dry, rodded volume of coarse aggregate per unit volume of concrete; b = solid volume of coarse aggregate per unit volume of concrete; and b_o = solid volume of coarse aggregate per unit volume of coarse aggregate.

NOTE: For concrete pavements or work in which there should be less mortar than required in the usual structural concrete, increase tabulated values of b/b_o about 10 percent. For concrete especially designed to be compacted by internal vibration under very rigid inspection, increase tabulated values of b/b_o about 15 per cent.

For highways (Here Mr. Goldbeck presented the following from National Crushed Stone Association, *Useful Information* No. 2—35, March 5, 1943):

Test Method for determining concrete proportions for a given beam strength

Concrete beam strength, expressed in terms of "Modulus of Rupture" is influenced greatly by the characteristics of the coarse aggregate as well as by other factors. Hence, at present, to determine the proportions of concrete required to produce a given beam strength, a laboratory procedure is necessary. The information given herewith will be of special interest to concrete engineers concerned with designing paving concrete and the values shown in the following table are particularly suitable for paving concrete, in which there should be sufficient mortar for workability, but not enough to produce a thick mortar wearing surface. The water contents suggested will produce approximately a slump of 2 inches. By the use of the values of dry, rodded volume of coarse aggregate shown in the table, in the manner illustrated in the example, the correct proportions for highway concrete will result.

Dry, Rodded Volume of Coarse Aggregate per Unit Volume of Highway Concrete (b/b_o)

Size of Coarse Aggregate Square Opening Laboratory Sieves	Fine Sand		Medium Sand			Coarse Sand			Approximate Gallons of Water per Cu. Yd. of Concrete for 2 in. Slump	
	Fineness Modulus of Sand								Coarse Aggregate	
	2.40 : 2.50		2.60 : 2.70 : 2.80			2.90 : 3.00 : 3.10			Angular	Rounded
No. 4 to 1 in.	.79	.78	.77	.76	.75	.74	.73	.72	35	31.5
No. 4 to 1½ in.	.81	.80	.79	.78	.77	.76	.75	.74	33	30
No. 4 to 2 in.	.84	.83	.82	.81	.80	.79	.78	.77	32	29
No. 4 to 2½ in.	.86	.85	.84	.83	.82	.81	.80	.79	31	28

b_o = solid volume of coarse aggregate per cu. ft. of dry, rodded, coarse aggregate.
b = solid volume of coarse aggregate per cu. ft. of concrete.
b/b_o = dry, rodded volume of coarse aggregate per unit volume of concrete.

The above table may be used for proportioning trial batches of concrete to determine the modulus of rupture. The bulk specific gravities of the sand and coarse aggregate; the dry, rodded weight per cu. ft. of coarse aggregate and the gradations of sand and coarse aggregate must first be obtained. The aggregates should be in a saturated surface-dry condition when making the concrete and the quantities of water shown are set up on that basis.

Example

What should be the proportions of trial batches of concrete made with limestone, No. 4—2 in. in size; sp. gr. = 2.70; dry, rodded weight = 100 lb. cu. ft.; sand, sp. gr. = 2.65; fineness modulus of sand = 2.80

From the above table $b/b_o = 0.80$
Solid weight of stone = $2.70 \times 62.4 = 168.5$

$$b_o = \frac{100}{168.5} = .593; \quad b = b/b_o \times b_o = .80 \times .593 = .475 = b$$

Assume a cement factor of 5 sacks per cu. yd.
Specific gravity of cement = 3.14
Solid weight of cement per cu. ft. = $3.14 \times 62.4 = 196$
Solid volume of cement per 94 lb. sack = $94/196 = 0.48$

	Solid Volumes	*Quantities per cu. yd.*	*per cu. ft.*
Cement.....5 × .48	= 2.4 × 196	= 470 lb. ÷ 27	= 17.4 lb.
Stone.....475 × 27	= 12.82 × 168.5	= 2160 lb. ÷ 27	= 80.0 lb.
Water.....32/7.5	= 4.27 = 32 gal. × 8.33 lb.	= 267 lb. ÷ 27	= 9.9 lb.
	27 −19.49 cu. ft.		
Sand.....7.51 cu. ft. solid volume × 165 lb.		= 1240 lb. ÷ 27	= 45.9 lb.
	Totals	4137 lb.	153.2 lb.

Similarly, calculations are made for 5.5, 6.0, 6.5 and 7.0 sacks, keeping b/b_o and total water constant and when the beam specimens made with proportions thus calculated are tested and the strength-cement factor curve is plotted, the cement factor and other quantities for the required strength may be obtained by interpolation.

For laboratory specimens, the aggregates should be saturated and surface dry, and the calculated dry aggregate weights should be increased by the weight of absorbed water. No change in weight of mixing water is necessary for these conditions.

The proportions as above determined must be corrected for use in the field so as to fully take into account the free moisture, the absorbed moisture and the absorption of the aggregates. (See N. C. S. A. Bulletin No. 11.)

It is best to specify proportions which require a higher cement factor than determined by the tests in order to allow for unforeseen contingencies incident to the work.

Sec. 3. When a table such as Table 2 is used, crushed aggregates are unjustifiably penalized by requiring more cement than with gravel, even when, with equal cement factor, the crushed aggregate may test higher than the gravel. This is frequently so, especially with the higher cement factors. Furthermore, the difference in concrete strengths as between crushed and rounded aggregates is generally less when the same cement factor is used than when the same W/C is used. The penalty imposed on crushed aggregates by Table 2 is not justified by the facts. I would substitute Table B based on equal cement factor.

Sec. 4. Note under Table 4 should read, "Based on square opening laboratory sieves.

Sec. 5. It is my belief that to use the percentages of sand specified in Table 5 irrespective of the gradation and fluctuation in shape within

TABLE B—CEMENT FACTORS (SACKS OF CEMENT PER CU. YD. OF CONCRETE) REQUIRED FOR 28-DAY COMPRESSIVE STRENGTHS LISTED

Size of coarse aggregate			No. 4 to ¾ in.		No. 4 to 1 in.		No. 4 to 1½ in.		No. 4 to 2 in.		No. 4 to 2½ in.	
Slump (in.)			3	6	3	6	3	6	3	6	3	6
Water, gal. per cu. yd. of concrete	Angular coarse aggregate		40	42	38	40	36	38	35	37	34	36
	Rounded coarse aggregate		36	38	34.5	36.5	33	35	32	34	31	33
28-day compressive strength lb. per sq. in.	2000	Sacks of cement per cu. yd. of concrete	4.6	4.9	4.4	4.6	4.2	4.4	4.1	4.3	4.0	4.2
	2500		5.0	5.3	4.8	5.0	4.5	4.8	4.4	4.6	4.3	4.5
	3000		5.5	5.8	5.2	5.5	4.9	5.2	4.8	5.1	4.7	4.9
	3500		6.0	6.3	5.7	6.0	5.4	5.7	5.2	5.5	5.1	5.4
	4000		6.5	6.8	6.1	6.5	5.8	6.1	5.7	6.0	5.5	5.8
	4500		7.1	7.4	6.7	7.1	6.3	6.7	6.2	6.5	6.0	6.3
	5000		7.7	8.1	7.3	7.7	6.9	7.3	6.8	7.1	6.5	6.9

NOTE: The 28-day strengths are the minimum values expected and should be used for design purposes. Laboratory specimens cured under ideal conditions will generally have higher strengths.

"rounded" coarse aggregates and "angular" coarse aggregates is incorrect. There may be a big difference in shape in angular aggregates which will require a difference in sand factor. The table sets up a difference of 5 per cent in sand factor between rounded and angular coarse aggregate and it ignores such important matters as the effect of differences in cement factor and differences in use for the concrete. It uses an extra table of corrections to care for these matters. I don't think this method is nearly as exact as our Tables 1 and 2 in National Crushed Stone Association Bulletin No. 11. (See preceding tables.)

In Table 5 under "Manufactured sand" I would add, "if sharp and angular." Some stone sands are actually more rounded than natural sands and require *less* water.

I think the example involving a pavement slab should be omitted.

Sec. 6. The assumption of "Absorption of water—negligible" for crushed stone with a specific gravity of 2.55 does not sound any too realistic. I believe 1 per cent absorption would be more nearly the truth.

With regard to the example—since I don't like the design method, I naturally don't like the example. It is confused also by the inclusion of the design for beam strength.

In the note referring to air voids, Section 6, instead of saying "a suitable allowance" why not say, "A reduction in solid volume of sand should be made equal to the volume of entrained air."

Sec. 9 (b). The paragraph is not clear—Why the empirical rules when calculation may be employed? The method of using percentage

of sand is by no means as simple as starting off with b/b_0. This is surely unnecessarily involved.

Section 10 simply adds to the confusion of a relatively simple matter.

The example in Section 6 should omit the flexural strength portion and this should be also omitted in Section 10. The procedure in Sec. 10 certainly would not be generally used except for very large jobs where extra refinements are essential. This should be made clear. Certainly this detailed study of mixes is not and need not be made on a very high percentage of concrete jobs.

Table 10 is somewhat ridiculous—Who, for instance, is going to use separated coarse aggregates of $\frac{3}{16}$ to 1 in. or even $\frac{3}{16}$ to $1\frac{1}{2}$ in. size on "small jobs"?

The report is unnecessarily complicated and it unjustifiably penalizes angular coarse aggregate by assuming that a given water-cement ratio is required for a given strength and a given degree of durability. The whole program of design is simplified by the use of proper values for b/b_0 and required cement factors. I would recommend that this method of design be used as an alternate, following the method described in N. C. S. A. Bulletin No. 11 and our Useful Information article, No. 2-35.

By C. W. BRITZIUS*

After a study of the report I have these comments to make:

I think that the proposed practice is very good and that it will be extremely useful because engineers will now be able to design concrete mixes accurately without laboratory facilities. I think the report is too voluminous for practical use. The section under "supplementary information" increases the size of the report and may prevent its use, yet I find the information in this section very useful.

Section 10 on laboratory experimental testing is interesting but tends to put reliance on mix design tables. Experimental work should be done by concrete engineers, who, because of their knowledge, would not require reference to tables such as these. In the usual job specification a few items only are specified, such as water cement ratio, cement factor and strength. When we design mixes under the terms of such specifications we design a series of mixes at cement content intervals of one-half sack. The data thus obtained enable us to determine the water-strength ratio relationship and makes it possible for us to select one of the three mixes designed.

I do not accept the inclusion of Section 11 in the report. The computation of a mix using the design tables provided is easy enough. When

*Twin City Testing & Engineering Laboratory, Inc., St. Paul, 4, Minn. This discussion, presented to Committee 613 in advance of the convention, was given convention presentation.

Table 10 is included, we are getting back to fixed proportions, as in the old 1:2:4 and 1:3:5 mixes.

Table 5 should contain some definition of "rounded coarse aggregate" and "angular coarse aggregate" so that interpolations may be made between the two. I assume that by rounded coarse aggregate is meant a rounded river gravel containing no crushed oversize. The angular coarse aggregate may mean a hard crushed rock containing extremely sharp flat and angular particles or may mean a limestone containing particles approximately cubical. The mixes for these two crushed aggregates would be different, the sharp crushed material requiring a higher cement and sand content than the cubical limestone. I suggest that under rounded coarse aggregate there be a table or column showing the void content for ½ in. maximum size, ¾, 1, 1½, 2, 3 and 6 in. This should also be done for the angular coarse aggregate. Interpolations can then be made accurately on the basis of the void content of the coarse aggregate for which the mix is being designed. On the basis of our data for the 1 in. maximum size, the void content should be 34 per cent for the round coarse aggregate and 40 per cent for the angular coarse aggregate. I have found that the void content of extremely angular and hard crushed rock will go as high as 44 per cent. As a result of this void content data, I have concluded that your table for angular coarse aggregate was set up for a crushed limestone and not for the extreme angularity encountered when using crushed granite, quartzite and trap rock.

I do not agree with the recommendation that engineers on the job adjust the computed mix; this should be done in the laboratory. Large projects will have laboratory equipment on the site and for smaller projects it should be done in some laboratory selected by the engineers. Such adjustments would be minor and would consist of increasing or decreasing the cement content perhaps as much as 2/10 of a sack per yard so that the required slump would be obtained using the required water-cement ratio. The main part of this laboratory check on the computed mix is the casting of test cylinders, with the cement to be used in the project to check the compressive strength. This standard strength determination is desirable in interpreting the results obtained from testing cylinders cast during the progress of the job.

By A. C. AVRIL*

In reading the committee report and putting it to practice in designing several mixes, it proves without a doubt, to be one of the most sensible and practical methods available for designing concrete mixes.

*Sackrete Inc., Cincinnati 23, Ohio. Submitted to Committee 613 prior to and presented at the convention.

Although only a few batches of different strengths and slumps were tried it was apparent that with reasonable care in following the recommended procedure, good results would be the rule rather than the exception, provided however, that strict control of aggregate gradation, moisture content and water ratio were observed.

The method is excellent but should not be considered the ultimate in concrete mix design. The committee implies this throughout the report. Specific mention of it is made here to stress further the importance of additional work toward the development of better methods, not only in the design of mixes, but in their control, in the productions of aggregate, and in the manufacture of cement. The industry needs, not only a good method for designing mixes, but greatly improved methods of control.

To the average man in the field, design and adjustment of the mix may appear somewhat involved because of the recommendation to carry the design through the steps allowing for retained moisture in the aggregate, before actually mixing the trial batch. It appears much simpler to confine the calculations and mixing of trial batches to the use of dried materials. This would reduce the possibility of error especially if a wide adjustment in sand content proves necessary because it would be natural to overlook the small amount of water in the added or subtracted amounts of sand with resultant difficulties in determining the true water-cement ratio. By using dried aggregate in the trial batches true proportions can be determined accurately leaving the adjustment for retained moisture in the job material simply to adding its weight to the design aggregate weights and subtracting it from the total water.

It has been found very convenient to mix the trial batches by hand in an amount equal to 1/100th of a cubic yard. This amount is just slightly in excess of enough to fill a slump cone or a 6 x 12-in. cylinder and reduces the hazard of mix segregation to a minimum, resulting in closer approximation to conditions throughout a large batch. Sampling from a three sack batch as recommended in the report, if carelessly done, could result in harmful adjustments of the mix.

If the trial mix is made with dried aggregate, and the procedure incorporates the data found in Tables 1 through 5, the trial mixes should be usable without further adjustment except to make corrections for the retained moisture.

It would be difficult to improve the trial mix on the job due to natural variations caused by present methods of producing, storing and handling concrete materials. In all probability the grading of no two batches would be alike, therefore, a fine adjustment of the mix on the job may do more harm than good.

It is not improbable that the fineness modulus of the sand may vary from 2.5 to 3.5 in a single day's run. Nor is it improbable that the fineness modulus of the coarse aggregate, assuming the maximum size to be one inch, would vary between 6.25 and 7.25. Combinations of materials varying so widely in gradation, assuming uniform moisture content, would result in a slump variation of from two to three inches and a range in workability from extremely undersanded mixes to those well oversanded. These variations in grading also have a marked effect on retained moisture in the aggregate amounting to a difference of as much as two per cent.

A two per cent difference in moisture content would cause a slump variation of about six inches, a difference in water ratio of about .15 and a difference in strength of more than 1000 psi in 28 days. These figures, based on actual tests, can be verified in the committee report or by making batches of concrete from samples of aggregate taken at random from either stock piles or bins.

These variables are mentioned to substantiate the suggestion that there should be at least one paragraph in the report dealing with segregation control in both bin and stock piles. The mere mention of different aggregate gradings affecting the quality of concrete is not enough because segregation is undoubtedly the greatest single factor contributing to the variations in concrete quality.

It is contended that nature plays a much bigger part in causing rejections by varying the physical properties of the ingredients than does careless workmanship. It would therefore be desirable not only to design a mix with representative materials but also with combinations representing the extremes so that engineers and inspectors on a project may know what variations in slump, workability and strength to expect.

This would prove the dependability of the engineers' mix design, the diligence of the inspector and the honesty of the material producer and the contractor. The recommended procedure to design mixes with representative materials reflects on the dependability of everyone concerned when wide variations in the properties of the concrete are encountered on the job, and may result in some drastic steps being taken to penalize everyone concerned for mistakes they, in reality, did not make. Therefore, it is not only necessary to have a scientific and practical method for designing concrete mixes, but also to have an accurate means for controlling concrete production from the source of materials to the forms.

The purpose of this discussion is to emphasize the fact that natural variables may undo all of the good accomplished by careful scientific mix design and that a uniformly strong, workable concrete cannot be

expected on the job unless suitable corrective measures are taken to control the uniformity of aggregate gradation and moisture content.

By W. H. THOMAN*

Forty years ago concrete with an ultimate strength of 2,000 psi, and questionable durability, was considered wonderful—today such concrete is poor. In early 1900 the mix was very dry, then practice swung to the other extreme of too much water, "soup"; but now pratice is back to a more rational basis. Much knowledge has been derived from the efforts of Fuller, Edwards, Abrams, Talbot, Richart, and a host of others too numerous to mention. Concrete passed from a chance conglomeration to a rationalized engineering material. It has passed from a material where 2,000 psi was fortunate to where 2,000 psi is unfortunate. Abrams' water-cement ratio law, Talbot and Richart's voids-cement ratio method and the constant water per unit volume of concrete give a rational basis for designing a mix of given strength and durability.

Along with our present day knowledge of concrete mixes and our improved mixing and placing equipment, is a more intimate knowledge of cement. The quality of cement has improved—greater uniformity, finer grinding, and higher strength. The rate of heat evolution has now become an important problem and has been partially controlled by predetermined composition of the cement. Volume change is bothersome, but research has shown considerable progress in controlling this characteristic. The knowledge of concrete is progressing but is not complete, and it must be kept in mind that no knowledge ever can be complete in a progressive art.

The committee has done an excellent job correlating in a systematic, clear, simple manner the necessary steps for the design of a concrete mix. The water-cement ratio is not the whole story, but certainly it is a basis for the design. At least, our knowledge of this relationship is more nearly complete than is our knowledge of the many other variables inherent in a concrete mix. It is a factor that affects the density, volumetric change, durability, and strength, and it is such an important factor that it should be the starting point and fixed factor for the design of a concrete mix. Table 1 is the key to the whole specification. Now I certainly do not wish to imply that to make good concrete, the only thing necessary is a given water-cement ratio. I've seen that tried by so-called concrete technicians with rather disastrous results. If satisfactory aggregates are used, that is, if the sand is free from organic matter and is low in silt, mica, or other injurious material, and the coarse aggregate is structurally sound, chemically inert, and reasonably free

*Associate Professor of Civil Engineering, University of Colorado, Boulder, Colo. Discussion presented to Committee 613 prior to and presented at the convention.

from flat and elongated particles and graded within the limits shown in Table 7, the strength of the mixture can be explained by the water-cement ratio theory.

Table 2 shows excellent average values but should be used on a basis of hopeful expectancy. The committee knows that this table of strength and water-cement relationship is strictly a helpful guide. Durability, however, has precedence over strength when the required water-cement ratio from Table 1 gives a lower value.

The apparent weakness in the specifications is the lack of emphasis given to the use of high frequency vibrators. A mix designed for placing without a vibrator is not satisfactorily designed for the use of a vibrator. Certainly this is worthy of a more important place in the specifications than a footnote under Table 3. Table 3 should list the maximum and minimum slump for vibrated concrete. Many contractors figure that the sole purpose of a vibrator is to cause the concrete to flow into the forms. Much excellent concrete has been ruined by the use of a vibrator. Also, Table 5 should include the approximate quantities for vibrated concrete. A distinction should be drawn between the conditions involved in designing a mix which is to be vibrated and one which is not.

Every concrete technician has his own pet method for designing a concrete mix. In most cases the final result is the same regardless of the method used. All technical methods lead to one end, an approximate mix. The final proportions are determined by the judgment of the designer. If the committee had included a discussion of these technical methods of design, the report would lose significance. We have been going around in circles for too many years and very often the acceptance of new knowledge is distressingly slow. Let us tie down a few fundamental relationships and add to them only as needed.

By W. H. PRICE*

There are so many good methods of designing concrete mixes that the committee has had a difficult time in arriving at a selected one. Mr. Goldbeck's method which he just described is a very good one, but I believe it is no better than the one finally selected by the committee.

Mr. Goldbeck starts by specifying the volume of rodded coarse aggregate per unit volume of concrete and arrives at the percentage of sand indirectly through the rodded unit weight of the coarse aggregate, estimated cement content and water content. For any given maximum size aggregate the difference in sand percentages due to the particle shape of the coarse aggregate is seldom found to be greater than 6 percent. Then, granting that the values given in Table 5 are within the

*Bureau of Reclamation, Denver; Member Committee 613—his remarks were made at the convention.

correct range, one should be able to select the percentage of sand, directly from this table, within 1 or 2 percent of that required for the desired workability. Granting that the b/b_o factors of Mr. Goldbeck are also within the correct range, a difference in the rodded unit weight determination of the coarse aggregate of 3 percent would produce a difference in the estimated sand percentage of about 2 percent. The unit weight of dry rodded aggregate can be increased by mechanical vibration by as much as 9 percent for the larger maximum sized aggregate. Therefore, it is entirely possible that different operators in different laboratories would obtain a difference of 3 percent in the rodded unit weight of a given aggregate. A comparison of some of the sand percentages determined by observation of trial mixes with those estimated by Mr. Goldbeck's method, showed a lack of agreement by more than 2 percent in the majority of cases.

These points of difference are brought out so that we can all realize how difficult it is to recommend a method of mix design, which would be satisfactory to everyone. I believe, however, that the committee has recommended a method that is workable and usable.

Just one more thing. Mr. Goldbeck criticized Table 2 of the report. I believe that anyone familiar with concrete at all realizes that a table of strengths such as this can give only average values and that the type and brand of cement will, in general, have more influence on the strength than the type and particle shape of the aggregate.

By A. H. YEATES and W. A. CORDON*

Since the publication of the "Proposed Recommended Practice for the Design of Concrete Mixes" in the November 1943 A.C.I. journal a series of laboratory concrete mixes have been made for investigating the following emperical values and rules given in the report:

(1) Recommended percentage of sand for concrete containing ¾-in. maximum aggregate in Table 5 of report.

(2) The grading limits listed in Table 7 of the report for 1½-in. maximum concrete.

(3) The range over which sand and cement can be interchanged as recommended on page 101 of the report without materially affecting the workability and slump of the concrete.

(4) Effect on workability and slump of interchanging sand and coarse aggregate as recommended in Table 5 of the report to compensate for changes in sand grading.

*Bureau of Reclamation, Denver, Colo. The discussion by Yeates and Cordon was submitted Mar. 7, 1944.

TABLE C—SAND GRADINGS, PER CENT RETAINED

Sieve Size	No. 1		No. 2		No. 3		No. 4		No. 5		No. 6	
	Ind	Cum	Ind	Cum	Ind	Cum	Ind	Cum	Ind	Cum	Ind	Cum
8	5	5	10	10	10	10	15	15	10	10	15	15
16	11	16	15	25	15	25	15	30	15	25	15	30
30	14	30	15	40	15	40	20	50	40	65	25	55
50	30	60	28	68	40	80	25	75	18	83	24	79
100	29	89	22	90	18	98	15	90	15	98	16	95
Pan	11	100	10	100	2	100	10	100	2	100	5	100
Total	100		100		100		100		100		100	
FM		2.00		2.33		2.53		2.60		2.61		2.74

Sieve Size	No. 7		No. 8		No. 9		No. 10		No. 11		No. 12	
	Ind	Cum	Ind	Cum	Ind	Cum	Ind	Cum	Ind	Cum	Ind	Cum
8	17	17	19	19	25	25	25	25	28	28	30	30
16	21	38	19	38	21	46	25	50	24	52	27	57
30	17	55	17	55	17	63	20	70	18	70	20	77
50	21	76	23	78	15	78	15	85	18	88	12	89
100	17	93	16	94	12	90	11	96	10	98	8	97
Pan	7	100	6	100	10	100	4	100	2	100	3	100
Total	100		100		100		100		100		100	
FM		2.79		2.84		3.02		3.26		3.36		3.50

Test procedure

A laboratory blend of 12 modified cements and a sound well-rounded aggregate having specific gravities of 2.77 for the coarse aggregate and 2.67 for the sand was used in the tests. The aggregate was cleanly separated into its various sizes and recombined in the desired proportions for each mix. The concrete was mixed in a "pan-type" mixer of approximately ⅔ cu. ft. capacity. The aggregate and cement were mixed dry for 30 seconds before the water was added. After adding the water, the concrete was mixed for three minutes before it was dumped into a shallow pan where it was turned over a few times with a shovel. Following this reworking two slumps were simultaneously taken, one in the usual manner and the other with the slump cone set in place in the Powers remolding apparatus. The workability of the concrete was observed and was also measured with the Powers remolding apparatus.† Prior to starting the series of concrete mixes, a series of mortar mixes was made for the purpose of determining the variations in water content for variations in sand gradings. The results of these mortar mix tests are presented in Table D and Fig. A.

†Described in "Studies of Workability of Concrete," by T. C. Powers, ACI JOURNAL, Feb. 1932; *Proceedings* V. 28, p. 419.

TABLE D—SERIES OF MORTAR MIXES TO DETERMINE THE EFFECT OF SAND GRADING ON WATER REQUIREMENT

Mix No.	Per cent Sand		Sand Grading No.	Mix Parts By Weight	W/C By Weight	Cement Content Bbl. per c.y.	Slump Inches	Water Content Lb. per c.y.	Unit Weight Lb. per c.f.	Compressive Strength Avg. 3 3" x 6" cyls.
	By Weight	By Absolute Volume								
1	100	100	11	1-2.5	0.418	2.64	4 3/4	413	143.6	8050
1a	100	100	11	"	0.390	2.67	2 1/4	392	144.7	8560
2	100	100	8	"	0.430	2.59	2 1/2	418	141.4	7230
3	100	100	6	"	0.433	2.56	2	417	140.5	7990
4	100	100	2	"	0.482	2.50	2 3/4	452	138.5	6790
5	100	100	3	"	0.473	2.49	2 1/4	443	137.7	6900
6	100	100	9	"	0.413	2.68	2 1/2	406		
6	100	100	9	"	0.438	2.61	5	430	143.1	7740
7	100	100	4	"	0.450	2.54	2 5/8	430	139.7	7070
8	100	100	5	"	0.450	2.53	2 5/8	428	139.3	7130

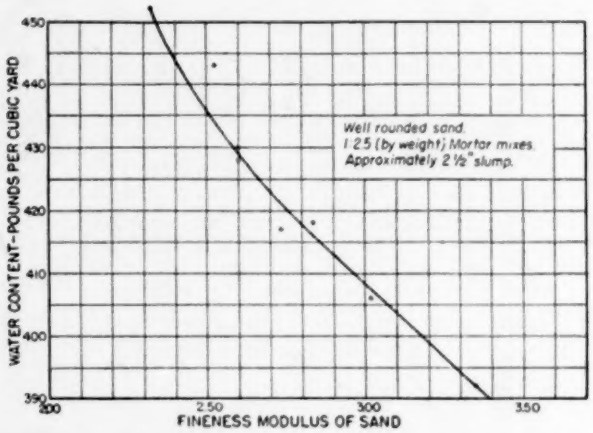


Fig. A—To maintain constant slump, the water requirement decreased as the fineness modulus of the sand was increased, however, observed workability decreased.

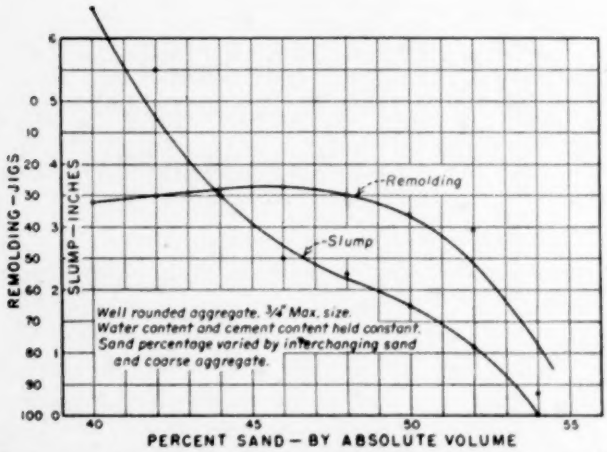


Fig. B—Slump decreased and workability increased slightly to an optimum then decreased as the percentage of sand was increased.

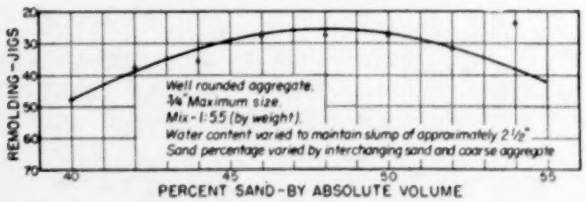


Fig. C—Slump held constant by varying water content, workability increased to an optimum and then decreased as sand percentage was increased.

TABLE E—SERIES TO DETERMINE THE OPTIMUM PERCENTAGE OF SAND FOR CONCRETE CONTAINING ROUNDED ¾ MAXIMUM SIZE AGGREGATE

Mix No.	Per cent Sand		Mix Parts By Weight	W/C by Weight	Cement Content Bbls. per c.y.	Slump Inches	Jigs Remoulding Apparatus	Water Content Lb. per c.y.	Unit Weight Lb. per c.f.	Compressive Strength Avg. 3-6" x 12" cyls.	Workability			Notes
	By Weight	By Absolute Vol.									Rodability	Finish	Segregation	
EFFECT OF PERCENTAGE OF SAND WHEN WATER CONTENT IS HELD CONSTANT														
1	39	40	1-5.5	0.514	1.56	6½	32	304	152.5	5150	Very good	Good	Slight	Very good concrete
2	41	42	"	0.514	1.55	5½	30	300	151.6	5250	Very good	Very good	None	Very good concrete
3	43	44	"	0.514	1.55	3½	28	299	151.1	5320	Very good	Very good	None	Very good concrete
4	45	46	"	0.514	1.54	2½	27	298	150.9	5420	Very good	Excellent	None	Excellent concrete
5	47	48	"	0.514	1.54	2¼	30	298	150.6	5020	Very good	Excellent	None	Excellent concrete
6	49	50	"	0.514	1.54	1¾	36	298	150.6	5140	Very good	Excellent	None	Very good concrete
7	51	52	"	0.514	1.54	1⅜	41	298	150.6	5290	Very good	Very good	None	Good concrete
8	53	54	"	0.514	1.53	0	93	295	149.1	5760	Good	Poor Sandy	None	Fair concrete, too dry
EFFECT OF PERCENTAGE OF SAND WHEN SLUMP IS HELD CONSTANT														
9	39	40	1-5.5	0.468	1.60	2⅝	48	281	154.8	6070	Good	Very good Very good	None	Good Concrete, slightly harsh
10	41	42	"	0.482	1.57	2⅜	38	284	152.5	5710	Good	Fat Very good	None	Very good concrete
11	43	44	"	0.496	1.55	2⅛	36	289	151.1	5490	Very good	Fat	None	Very good concrete
12	45	46	"	0.514	1.54	3¼	28	298	150.6	5540	Very good	Very good	None	Excellent concrete
13	47	48	"	0.514	1.54	2¾	28	297	150.4	4950	Very good	Very good Very good	None	Very good concrete
14	49	50	"	0.525	1.53	3	28	301	150.0	4670	Excellent	Sandy Very good	None	Very good concrete sandy
15	51	52	"	0.532	1.52	2½	32	305	149.2	4710	Excellent	Sandy Very good	None	Good concrete, sandy
16	53	54	"	0.550	1.51	2½	24	313	148.5	4280	Excellent	Sandy	None	Good concrete, sandy

NOTES: Coarse aggregate grading—45 per cent ⅛" to ⅜", 55 per cent ⅜" to ¾"
Sand grading No. 6 used for all mixes.

TABLE F—SERIES TO CHECK GRADING LIMITS FOR FINE AND COARSE AGGREGATES IN 1½" MAXIMUM SIZE AGGREGATE CONCRETE

Mix No.	Parts of Aggregate By Weight	Per cent Sand		Sand		Coarse Aggregate				Net W/C By Wt.	Slump, Inches	Remldg. Apparatus		Unit Wt. Fresh Conc. Lb. per Cu. Ft.	Water Content Lb. per Cu. Yd.	Cement Content Bbl. per Cu. Yd.	Unit Comp. Strength psi 28 days	Workability			Notes
		By Weight	By Abs. Vol.	No.	F. M.	Fineness Modulus	Grading No. 4-⅜	Grading ⅜-¾	Grading ¾-1½			Jigs	Slump					Rodability	Finish	Segregation	
1	6.66	33.3	34.2	1	2.00	6.90	40	30	30	.51	⅜	76	½	155.3	262	1.37	4970	Fair	Good Glassy	None	Good concrete, slightly rocky, crumbly
2	6.66	33.3	34.2	1	2.00	6.95	35	35	30	.51	1	67	1⅛	154.4	260	1.36	5000	Fair	Good Glassy	None	Good concrete, slightly rocky, crumbly
3	6.66	33.3	34.2	1	2.00	7.05	30	35	35	.51	1¾	60	1⅞	155.1	261	1.36	5030	Fair	Very good	Slight	Very good concrete, slightly crumbly
4	6.66	33.3	34.2	1	2.00	7.17	25	33	42	.51	1½	55	1½	155.1	261	1.36	4830	Good	Very good Fat	None	Good concrete, rocky
5	6.66	33.3	34.2	1	2.00	7.30	20	30	50	.51	2	58	2	154.9	261	1.36	4660	Good	Very good Fat	None	Good concrete, rocky
6	6.66	33.3	34.2	1	2.00	7.45	15	25	60	.51	2	71	2½	155.1	261	1.36	4540	Good	Very good Fat	Slight	Good concrete, rocky
7	6.66	35	35.8	2	2.33	6.90	40	30	30	.51	1¾	61	1⅜	155.2	261	1.36	4740	Good	Good, Sl. Harsh	None	Good concrete, harsh, slightly crumbly
8	6.66	35	35.8	2	2.33	6.95	35	35	30	.51	1¾	76	1½	154.7	261	1.36	4950	Good	Good	None	Good concrete, slightly harsh, crumbly
9	6.66	35	35.8	2	2.33	7.05	30	35	35	.51	2	49	2¾	155.4	262	1.37	4580	Good	Very good	Slight	very good concrete, slightly rocky
10	6.66	35	35.8	2	2.33	7.17	25	33	42	.51	2⅛	46	2¼	155.2	261	1.36	4950	Good	Good Fat	None	Very good concrete, slightly rocky
11	6.66	35	35.8	2	2.33	7.30	20	30	50	.51	2¾	54	2¾	154.6	260	1.36	4850	Good	Very good Fat	Slight	Very good concrete, rocky
12	6.66	35	35.8	2	2.33	7.45	15	25	60	.51	2¾	66	2¾	155.0	261	1.36	4570	Good	Very good Fat	Slight	Good concrete, rocky
13	6.66	37	37.9	7	2.79	6.90	40	30	30	.51	2¼	73	2	154.8	261	1.36	5280	Good	Fair	None	Good concrete, slightly crumbly
14	6.66	37	37.9	7	2.79	6.95	35	35	30	.51	2½	58	2	155.0	261	1.36	4940	Good	Good	None	Good concrete, slightly crumbly
15	6.66	37	37.9	7	2.79	7.05	30	35	35	.51	3	54	3½	155.8	262	1.37	5080	Good	Good	None	Very good concrete
16	6.66	37	37.9	7	2.79	7.17	25	33	42	.51	3½	53	3½	155.0	261	1.36	4780	Good	Very good	None	Very good concrete
17	6.66	37	37.9	7	2.79	7.30	20	30	50	.51	4	60	3¾	154.9	261	1.36	4650	Fair	Very good	Slight	Very good concrete, slightly rocky
18	6.66	37	37.9	7	2.79	7.45	15	25	60	.51	3¾	75	3	155.7	261	1.36	4620	Fair	Good	Some	Good concrete, rocky

19	6.66	39.5	40.4	10	3.26	6.90	40	30	30	.51	2¼	63	2	154.7	261	1.36	4560	Very good	Fair Sandy	None	Good concrete, harsh, Very crumbly
20	6.66	39.5	40.4	10	3.26	6.95	35	35	30	.51	2½	78	2	155.0	261	1.36	4760	Very good	Fair Sandy	None	Good concrete, harsh, crumbly
21	6.66	39.5	40.4	10	3.26	7.05	30	35	35	.51	3	62	3	155.5	262	1.37	4390	Very good	Fair Sandy	Slight	Good concrete, harsh
22	6.66	39.5	40.4	10	3.26	7.17	25	33	42	.51	3½	61	3¾	155.2	262	1.37	4300	Good	Good Sandy	Slight	Very good concrete, slightly rocky & harsh
23	6.66	39.5	40.4	10	3.26	7.30	20	30	50	.51	4¾	71	4	155.2	262	1.37	4230	Good	Fair Sandy	Slight	Good concrete, rocky
24	6.66	39.5	40.4	10	3.26	7.45	15	25	60	.51	4¼	70	4¼	155.4	262	1.37	4360	Fair	Fair Sandy	Some	Good concrete, rocky
25	6.66	40.8	41.6	12	3.50	7.05	30	35	35	.51	2¼	66	3¼	154.7	261	1.36	5270	Good	Poor Harsh	Some	Poor concrete, very harsh, crumbly
26	6.66	40.8	41.6	12	3.50	7.17	25	33	42	.51	3	70	3½	155.7	262	1.37	4980	Good	Poor Harsh	Consider-able	Fair concrete, harsh
27	6.66	40.8	41.6	12	3.50	7.30	20	30	50	.51	2½	90	2	154.5	260	1.36	5090	Good	Fair	Consider-able	Fair concrete, harsh, slightly rocky

TABLE G—COMPARISON OF THE WORKABILITY OF CONCRETE IN WHICH THE SAND AND CEMENT WERE INTERCHANGED BY EQUAL ABSOLUTE VOLUME AND IN WHICH THE WATER CONTENT WAS HELD CONSTANT

Mix No.	Sand No.	Parts of Aggregate	Per cent Sand	Net W/C by Wt.	Slump Inches	Jigs in Remoulding Apparatus	Unit Wt. Fresh Concrete	Water Content Lb. per Cu. Yd.	Cement Content Bbl. per Cu. Yd.	Compressive Strength Avg. 3-6" x 12" cyls.	Workability			Notes:
											Rodability	Finish	Segregation	
	¾" Maximum Aggregate:													
1	6	4.3	43	0.42	3	31	152.4	304	1.93	5670	Very good	Excellent Glassy	None	Very good concrete
2	6	5.5	45	0.52	3¾	23	150.8	302	1.54	4300	Very good	Excellent Fat	None	Very good concrete
3	6	6.7	46	0.62	3¾	23	150.1	302	1.30	3470	Very good	Very good Sandy	None	Very good concrete slightly sandy
4	6	7.9	47	0.72	3¾	26	150.6	304	1.13	2890	Very good	Very good Sandy	None	Very good concrete lean, sandy
	1½" Maximum Aggregate:													
5	7	5.97	38.0	0.53	2¾			285	1.43		Very good	Very good	None	Very good concrete
6	7	4.71	35.9	0.43	2¾			285	1.76		Very good	Very good Fat	None	Very good concrete slightly rocky and sticky
7	7	7.25	39.3	0.63	3			285	1.20		Excellent	Very good	None	Very good concrete slightly sandy
8	7	9.82	40.9	0.83	2½			285	0.91		Excellent	Very good	None	Very good concrete lean, sandy, slight bleeding

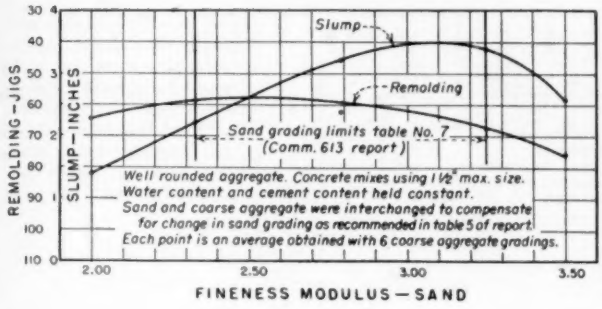
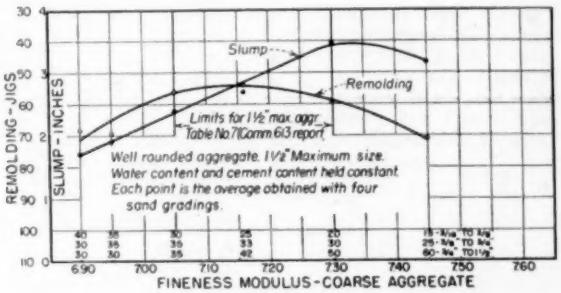

Slump
Remolding
Sand grading limits table No. 7 (Comm. 613 report)
Well rounded aggregate. Concrete mixes using 1½" max. size.
Water content and cement content held constant.
Sand and coarse aggregate were interchanged to compensate for change in sand grading as recommended in table 5 of report.
Each point is an average obtained with 6 coarse aggregate gradings.
REMOLDING—JIGS
SLUMP—INCHES
FINENESS MODULUS—SAND

Fig. D—Workability and slump increased to an optimum and then decreased as the fineness modulus of the sand was increased with corresponding increase in sand percentage.

Fig. E—Workability and slump increased to an optimum and then decreased as the fineness modulus of the coarse aggregate was increased.


Slump
Remolding
Limits for 1½" max. aggr. Table No 7 (Comm 613 report)
Well rounded aggregate. 1½" Maximum size.
Water content and cement content held constant.
Each point is the average obtained with four sand gradings.
REMOLDING—JIGS
SLUMP—INCHES
FINENESS MODULUS—COARSE AGGREGATE

Two series of mixes were made to determine the optimum percentage of sand for concrete containing ¾-in. maximum aggregate. The sand used in this series had an F.M. of 2.74. In one the mix parts, water-cement ratio and water content, were held constant and the slump allowed to vary with changes in sand percentages. In the other series the mix parts were held constant, but the water content was varied to maintain a constant slump as the requirements changed for different percentages of sand. The grading of the sand and coarse aggregate was maintained constant for both series. The results of these two series are given in Table E and are plotted on Fig. B and C.

A series of 27 mixes containing 1½-in maximum aggregate were made to investigate the grading limits listed in Table 7 of the report and the effect of interchanging sand and coarse aggregate to compensate for changes in sand gradings as recommended in Table 5 of the report. In this series five gradings of sand which varied in fineness modulus from 2.00 to 3.50 and six gradings of coarse aggregate, three within and three outside those recommended in Table 7 of the report were used. The water-cement ratio, cement content, and water content of these mixes were held constant. The results of this series are shown on Table F and are plotted on Fig. D and E.

Two series of mixes containing 1½- and ¾-in. maximum aggregates, respectively, were made with the absolute volume of the coarse aggregate

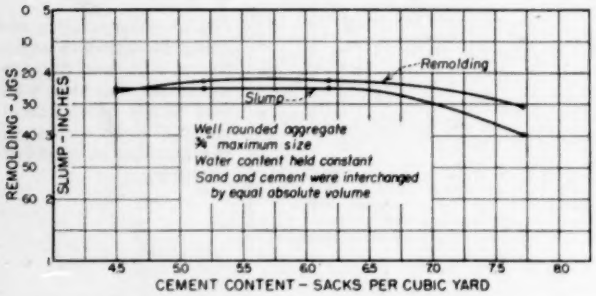
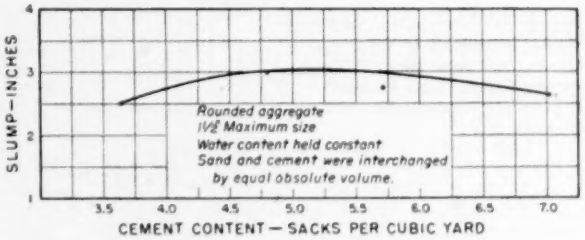


Fig. F—Workability and slump remained essentially constant for wide range in cement content when water content was held constant and sand and cement were interchanged by equal absolute volume.

Fig. G—Slump remained essentially constant for wide range in cement content when water content was held constant and sand and cement were interchanged by equal absolute volume.


SLUMP – INCHES
Rounded aggregate
1½" Maximum size
Water content held constant
Sand and cement were interchanged
by equal absolute volume.
CEMENT CONTENT – SACKS PER CUBIC YARD

and water content held constant and the water-cement ratio, and cement content varying over a wide range to determine the range over which sand and cement could be interchanged without materially affecting the workability. The results of this series are shown on Table G and plotted on Fig. F and G.

Discussion of results

By referring to Table 3 and Fig. 2 and 3, it can be seen that for a rounded aggregate and average sand grading used in the tests that the optimum workability is obtained with 46 percent sand as recommended in Table 5 of the report. However, the results also show that the percentage of sand, for concrete containing ¾-in. maximum aggregate, can be varied over comparatively a wide range with no material effect on the workability of the concrete.

The results of the series made to investigate the aggregate gradings listed in Table 7 for 1½-in. maximum concrete and the interchange of sand and coarse aggregate showed that if the percentage of sand is changed by ± ½ percent for each 0.1 change in F.M. of the sand as recommended in the report that the slump and workability of the concrete will not remain constant even in the limits of grading given in Table 7. It is indicated from these tests that a slightly larger change in sand percentage should be made for changes in F.M. The results also showed that when sands having a fineness modulus less than 2.33 (the finest grading recommended in Table 7) are used, the slump takes a sharp drop,

and when sands having a fineness modulus coarser than 3.26 (the coarsest grading recommended in Table 7) are used, the concrete becomes harsh and unworkable. In the case of the coarse aggregate the tests showed that the grading of the coarse aggregate has a material influence on the slump and workability of the concrete, and that there is a drop in workability when gradings outside the recommended limits are used.

The results of the series of mixes in which cement and sand were interchanged by equal absolute volume showed that when this interchange is made, as recommended in section 7, page 101 of the report, that the richness of the mix and water-cement ratio can be varied over a wide range without materially affecting the workability and slump of the concrete.

The particular aggregate and cement used in these tests required about 20 pounds less water than the average listed in Table G of the report. Such a variation from the average, however, is not uncommon and the results in general are considered to be in good agreement with the report.

CONVENTION ACTION ON THE REPORT

Committee Chairman R. F. Blanks proposed the three amendments. They were adopted, without dissent, as follows:

Page 107 under "(c) Concrete mix tests," combine paragraphs 2 and 3, with the deletion of all of paragraph 2 except the first sentence, and the deletion of the first sentence of paragraph 3 to effect a new paragraph 2 as follows:

> The trial mix, as calculated in Section 6, provides a starting point for the laboratory test series. Five additional mixes are then made with the water-cement ratio varying over a total range of 0.20 to establish water-cement ratio strength relationships. For this set of mixes the percentage of sand is varied according to the water-cement ratio, or richness of mix, as indicated in the recommended procedure.

(Chairman Blanks called attention to the fact that this amendment entailed the deletion of Mixes 1, 2 and 3 from Table 8, p. 108, and renumbering "Trial" and Mix numbers 4 to 8, to become 1 to 6).

From page 106 under "(b) Physical properties of aggregate" in section 10, "Laboratory Tests" delete the entire fourth paragraph that begins, "Table 7 may be useful"; and delete Table 7 from page 107.

From Table 10, page 111, delete column 3, under the heading, "Mix by Weight." Delete all of columns 6, 7, 8, 9 and 10—all but the first and final columns under the heading "Pounds of Aggregate per 1-Sack Batch."

EDITORIAL REVISIONS DESIGN OF CONCRETE MIXES

The following, in further reference to changes in the Report of Committee 613 is a statement from chairman Robert F. Blanks (Apr. 4) covering "editorial revisions."

He had pointed out at the beginning of the convention session that the proposed amendments, which had been unanimously agreed upon at a meeting of the Committee on the previous day, would require certain editorial revisions and adjustments and that, in addition, a very few editorial corrections were required in the report as published in the November 1943 JOURNAL. These are listed as follows:

p. 94, lines 7 and 20—Insert "1 of the appendix" in place of "10".

p. 96, line 7,—Insert "1 of the appendix" in place of "10".

p. 97, second and third lines from bottom of page, delete "in addition to that described in section 10".

p. 98, line 7, delete "(section 10)." Table 5, insert "(sharp and angular)" after "Manufactured sand."

p. 99, line 13, delete "air-dry" and insert "(saturated surface-dry)."
Line 16, delete "(Absorption of water—Negligible)".
Line 22, insert "(1-c) of the appendix" in place of "(10-c)".
Lines 23 and 24, revise sentence to read: From Tables 3 and 4 it is concluded that for the concrete in the retaining wall, a three-in slump and 1½-in. maximum aggregate will be satisfactory."

p. 100, Second line of narrative—Insert "(1-c) of the appendix" in place of "(10-c)".
At end of footnote—insert "replacing an equal volume of sand" in place of "an additional ingredient".

p. 101, at end of note near top of page—insert "3 of the appendix" in place of "9."
Change center heading "Supplementary Information" to "Appendix."
In subheading near bottom of page change "8" to "2."

p. 103, before subheading near middle of page change "9" to "3."
In second to last line on page, change "6" to "8."

p. 104, change "Table 6" to "Table 8." In sixth column of Case I, insert "*" before "Directly."
Change footnote (2) to read "Approximate cement content for unit weights shown in footnote (3)."
Insert footnote "* For all practical purposes."

p. 105, before subheading "Laboratory Tests" change "10" to "1" and move this section up to become the first section of the Appendix.

p. 106. (Fourth paragraph deleted by Convention amendment).
In last line on page, insert "aggregate" for "source or sources" and delete "The sand and coarse."

p. 107, from first line, delete "aggregate should be washed, if required," and start new sentence with "The coarse aggregate should be cleanly separated . . ."
(Table 7 and footnote deleted by Convention amendment.)
At end of first full paragraph, change "8 and 9" to "6 and 7."

(Convention amendment deleted all but the first sentence from the next to the last paragraph and the first sentence of the last paragraph.)

p. 108. Change "Table 8" to "Table 6". In first line of tabulated data, substitute 1:2.32:3.08 for 1:2.3:3.1.

(Convention amendment deleted mixes No. 1, 2, and 3 from Table 8; inserted "1" for "Trial" in first column and substituted 2, 3, 4, 5, 6, for 4, 5, 6, 7, 8 in the first column.

p. 109, line 4—change "9" to "7."

Line 5, replace "no longer necessary" by "unnecessary."

Lines 8 to 10, delete "and that a sand . . . . for pavement slab."

Line 11, delete "and sand content of 40 per cent."

Line 14, change "8" and "9" to "6" and "7" respectively.

In Table 9 heading, change "9" and "8" to "7" and "6" respectively.

In top line of table, change "4090" to "4390"; "575" to "610" and "4540" to "5000."

In same table delete second and third lines of tabulated data and substitute 2, 3, 4, 5, 6 for 4, 5, 6, 7, 8 in first column.

In tenth line from bottom of page, change "8" to "6."

p. 110, top line, change "8" and "9" to "6" and "7."

In line 4, insert "different percentages of sand," after "aggregate gradings."

Line 29, delete "Organic impurities in sand—AASHO Designation: T21", Line 32, insert "and magnesium" after "Sodium."

Line 34, delete "Soundness—Freezing and Thawing method—AASHO Designation: T103."

p. 111. Before subheading near top of page, change "11" to "4."

To last sentence preceding Table add "using aggregate of average specific gravity."

In table heading change "10" to "9." (Convention amendment deleted third column and columns listing weights of the separate sizes of coarse aggregate from table.)

Add footnote "For slag, use 85 per cent of coarse aggregate weights shown."

A part of PROCEEDINGS OF THE AMERICAN CONCRETE INSTITUTE Vol. 40

JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

Vol. 15 No. 2 7400 SECOND BOULEVARD, DETROIT 2, MICHIGAN November 1943

Proposed Specifications for Concrete Pavements and Bases*

REPORTED BY ACI COMMITTEE 617

H. F. CLEMMER, Chairman

R. D. BRADBURY
A. T. GOLDBECK
FRED HUBBARD
FRANK H. JACKSON
BAILEY TREMPER
STANTON WALKER

SCOPE

1. Concrete pavement and base

These specifications apply to the construction of portland cement concrete pavement and base under normal conditions, including the preparation of the subgrade, and shall govern unless modified by special provisions to take into account unusual conditions of traffic, subgrade, drainage, exposure and other factors.

MATERIALS

2. Approval of sources of material supply

Portland cement, aggregates and water shall be furnished only from sources of supply approved by the engineer before shipments are started. The basis of approval of such sources shall be the ability to produce materials of the quality and in the quantity required.

3. Portland cement

(*a*) Cement shall conform to the requirements of the current American Society for Testing Materials Standard Specifications for Portland Cement (Designation C 150). Type I cement shall be supplied unless Type II (Moderate Heat of Hydration) or Type III (High Early Strength) is required by the special provisions.

(*b*) Cement shall be protected from the weather and against loss in handling or in transit. Either package or bulk cement may be used.

*Received by the Institute Sept. 29, 1943, as released by the Standards Committee for publication and for convention consideration on a motion for adoption as an ACI Standard.—Reference is made to a previous report of Com. 617 published ACI JOURNAL, Feb. 1941 and given formal presentation for discussion at the 1941 convention.

4. Aggregates

(*a*) Aggregates shall conform to the requirements of the current ASTM Standard Specifications for Concrete Aggregates (Designation C 33).

Note: It will be necessary to include limits in these specifications to meet local conditions.

Coarse aggregate shall be furnished in two separate sizes with the separation at the ¾-in. sieve when combined material graded from No. 4 to 1½ in. is required, and at the 1-in. sieve when combined material graded from No. 4 to 2 in. is required.

(*b*) In arranging for storage of aggregates, positive means shall be used to prevent the inclusion of foreign material. Aggregates shall not be placed upon the finished subgrade. Aggregates of different kinds and sizes shall be placed in different stock piles. Stock piles of coarse aggregates shall be built up in successive horizontal layers not more than 3 ft. thick. Each layer shall be completed before the next is started. Should segregation occur, the aggregates shall be remixed to conform to the grading requirements.

(*c*) Frozen aggregates or aggregates containing frozen lumps shall be thawed before use. Washed aggregates and aggregates produced or manipulated by hydraulic methods shall be allowed to drain for at least twelve hours before use. Stock piles or cars and barges equipped with weep holes are considered to offer suitable opportunity for drainiage.

5. Water

Water used in mixing or curing concrete shall be clean and free from injurious amounts of oil, salt, acid, vegetable or other substances harmful to the finished product. Sources of water shall be maintained at such a depth, and the water shall be withdrawn in such a manner (by enclosing pump intake, etc.), as to exclude silt, mud, grass or other foreign materials.

6. Reinforcement steel and accessories

(*a*) *Steel wire fabric.* Steel wire fabric reinforcement shall conform to the requirements of the current ASTM Standard Specifications for Welded Steel Wire Fabric for Concrete Reinforcement (Designation: A 185).

(*b*) *Bar mats.* The steel in bar mats shall conform to the requirement of the current ASTM Standard Specifications for Bar or Rod Mats for Concrete Reinforcement (Designation: A 184). Members shall be of the size and spacing shown on the plans. All intersections of longitudinal and transverse bars shall be securely wired, clipped or welded together.

(*c*) *Dimensions of wire fabric and bar mats.* The width of fabric sheets or bar mats shall be such that, when properly placed in the work, the extreme longitudinal members of the sheet or mat will be located not less

than 3 in. nor more than 6 in. from the edges of the slab. The length of fabric sheets or bar mats shall be such that, when properly placed in the work, the reinforcement will clear all transverse joints by not less than 2 in. nor more than 4 in. as measured from the center of the joint to the tip ends of the longitudinal members of the sheet or mat.

(*d*) *Bars.* Reinforcement bars shall conform to the requirements of the current ASTM Standard Specifications for Billet-Steel Bars for Concrete Reinforcement (Designation: A 15) or for Rail-Steel Bars for Concrete Reinforcement (Designation: A 16). Bars depending upon bond for their effectiveness shall be free from excessive rust, scale, or other substances which prevent the bonding of the concrete to the reinforcement.

(*e*) *Tie bars.* Tie bars shall be deformed steel bars conforming to the requirements of the specifications for reinforcement bars except that rail steel bars shall not be used where they are to be bent and restraightened.

(*f*) *Dowels and sleeves.* Dowels shall be plain round bars conforming to the requirements of the specifications for reinforcement bars.

When metal sleeves are used they shall cover the ends of the dowels for not less than 2 in. nor more than 3 in. The sleeve shall be closed at one end. It shall have a suitable stop to hold the end of the bar at least 1 in. from the closed end of the sleeve. It shall be of such rigid design that the closed end will not collapse during construction.

(*g*) *Chairs.* Chairs for holding tie rods in correct position while the concrete is being placed shall be of metal, slightly rounded and tapered at one end. The minimum dimensions shall be: Thickness 16 gauge (U. S. Standard Gauge 1893), length 12 in., width 1¾ in. measured along the metal.

(*h*) *Stakes.* Stakes used to support expansion joint fillers shall be channel- or U-shaped, at least ¾ in. wide and ⅜ in. deep and of metal not thinner than 16 gauge (U. S. Standard Gauge 1893). They shall be 15 in. long or longer if required to provide proper bearing support.

7. Subgrade paper

Subgrade paper shall conform to the requirements of the current American Association of State Highway Officials Standard Specification for Subgrade Paper, M 74.

8. Expansion joint filler

Expansion Joint Filler shall conform to the requirements of the current ASTM or AASHO Standard Specifications for Preformed Expansion Joint Fillers for Concrete.

9. Metal joint plate and pins

Plates for tongue and groove joints shall be steel or iron not thinner than 16 gauge, (U. S. Standard Gauge, 1893). Each section shall be a

continuous strip of metal not more than 15 ft. long having a width ½ in. less than the depth of the pavement; it shall be provided with an end connection which will hold the ends of strips firmly together. Each section shall be of the specified cross section, and shall be punched for dowels or tie bars, and pins, as shown on the plans.

Pins shall be channel shaped, pressed out of sheet steel of not less than 12 gauge (U. S. Standard Gauge, 1893) and not less than 15 in. long.

10. Cover materials for curing

(*a*) *Burlap.* Burlap shall be made from jute or hemp and, at time of using shall be in good condition, free from holes, dirt, clay, or any other substance which interferes with its absorptive quality. It shall not contain any substance which would have a deleterious effect on the concrete. Burlap shall be of such quality that it will absorb water readily when dipped or sprayed and shall weigh not less than 7 oz. per square yard when clean and dry. Burlap made into mats may be used if care in handling is exercised to avoid marring the finished surface of the concrete.

(*b*) *Cotton mats.* Cotton mats for curing concrete shall conform to the requirements of the current AASHO Standard Specifications for Cotton Mats for Curing Concrete Pavements. (Designation M 73).

11. Testing materials

Materials shall be tested in accordance with methods referred to in the appropriate specifications, except as otherwise specified.

12. Flexural strength tests of concrete as basis of design

Flexural strength tests to be used as the basis for the design of concrete mixtures shall be carried out in accordance with the current ASTM Standard Method of Test for Flexural Strength of Concrete. (Laboratory Method Using Simple Beam with Third Point Loading, Designation C 78).

13. Flexural strength tests of concrete for field control

(*a*) Flexural tests of concrete specimens molded and cured in the field shall be made, whenever feasible, using the testing machine described in ASTM Method C 78. Field Cured Specimens should not be used as a basis for design of mixtures. If another type of testing machine is used, results obtained with it should be correlated with those obtained from the standard apparatus. Apparatus for making flexure tests of concrete shall be so designed as to incorporate the following principles:

(1) The distance between supports and points of load application shall remain constant for a given apparatus.

(2) The load shall be applied normal to the initial position of the neutral surface of the beam and in such a manner as to avoid eccentricity of loading.

(3) The direction of the reactions shall, at all times during a test, be parallel to the direction of the applied load.

(4) The load shall be applied at a uniform rate and in such a manner as to avoid shock.

(5) The ratio of distance between point of load application and nearest reaction to the depth of the beam shall not be less than one.

Note: The directions of loads and reactions may be maintained parallel by judicious use of linkages, rocker bearings and flexure plates. Eccentricity of loading can be avoided by use of spherical bearings.

(*b*) *Molding, curing and marking.* Concrete for the field test specimens shall be secured in accordance with the current ASTM Method of Sampling Fresh Concrete (Designation: C 172) from the concrete deposited on the subgrade. The specimens shall be molded and finished as described in the current ASTM Method of Test for Flexural Strength of Concrete (Designation C 78). They shall be cured, as nearly as practicable, in the same manner as the pavement concrete. They shall be properly identified as to date of molding and location of pavement represented; weather conditions prevailing at the time of molding shall be noted.

(*c*) *Number of specimens.* At least two beams shall be made for each one thousand square yards of pavement.

14. Specific gravity and absorption of aggregates

(*a*) *Fine aggregate.* The bulk specific gravity and absorption of fine aggregate shall be determined in accordance with the current ASTM Standard Method of Test for Specific Gravity and Absorption of Fine Aggregates. (Designation C 128).

(*b*) *Coarse Aggregate.* The bulk specific gravity and absorption of coarse aggregate shall be determined in accordance with the current ASTM Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate. (Designation C 127).

15. Consistency

Consistency shall be determined in accordance with the current ASTM Standard Slump Test for consistency of concrete. (Designation C 143).

PROPORTIONS OF MATERIALS

16. Basis of proportions

The proportions of water, cement and aggregates shall be in accordance with *Proportions based on design for minimum strength* (Section 17) or in accordance with *Proportions based on uniform cement factor* (Section 18) as specified in the special provisions.

17. Proportions based on design for minimum strength

(*a*) The proportions of cement, fine aggregate, coarse aggregate and water to be used in the mix shall be determined by the Engineer, within the limits of Sections 17(b) and 17(c), by means of laboratory tests of the flexural strength of concrete made with aggregates from the same

sources and of the same gradings as will be employed in the work and that portland cement which is found to produce the lowest strength concrete of any acceptable cement available for the work.

(*b*) The mixture determined upon shall produce workable concrete having a slump of 2 in. to 3 in. for unvibrated concrete, or ½ in. to 1½ in. for vibrated concrete, and a modulus of rupture at 14 days of not less than 550 psi as determined from specimens made, cured and tested in accordance with the current ASTM Method C 78.

(*c*) The resulting proportions shall be such that the mixing water, including free surface moisture on the aggregates but exclusive of moisture absorbed by the aggregates, shall not exceed 6 gal. per sack of cement for any individual batch in localities where the concrete will be subjected to severe freezing and thawing conditions. In no case shall the mixing water exceed 6½ gal. per sack of cement for any individual batch. The cement content shall be not less than 5 sacks per cubic yard.

(*d*) Unless otherwise specified in the special provisions the following requirements shall govern the contractural relations concerning proportions based on design for minimum strength:

(1) Upon request, the Engineer will furnish prospective bidders with information as to the proportions by weight required for aggregates from established sources available for use on the project. This information will also include the grading of the aggregates used in determining these proportions.

(2) Promptly after receipt of notice of award of the contract, the Contractor shall furnish the Engineer with the location, or locations of the source or sources of aggregates which he proposes to use. The proportions will be designated by the Engineer. Except as hereinafter provided the designated proportions shall govern as long as materials are furnished from the sources designated and as long as they continue to meet the requirements specified.

(3) If, during the progress of the work, the contractor proposes to use aggregates from approved sources other than those originally designed, the Engineer will designate the new proportions to be used.

(4) If satisfactory plasticity and workability are not secured using the proportions and aggregates originally designated, the engineer may alter such proportions. If such alterations change the designated cement factor originally fixed by 2 per cent or less, no adjustment in the amount paid the contractor shall be made. If such alterations change the designated cement factor by more than 2 per cent, the source and quality of the aggregates remaining the same, payment shall be adjusted for or against the contractor in whatever amount the total cost of materials, f.o.b. contractor's material yard, has been increased or decreased by more than 2 per cent. The calculation of the amount of such increase or decrease shall be based upon the designated cement factor and not on count of bags of cement used or of the batches where bulk cement is used.

18. Proportions based on uniform cement content

(*a*) The proportions herein specified have been shown by experience to give satisfactory results for materials meeting the requirements of these specifications. They are so fixed as to produce concrete of constant

yield for all types of materials meeting the requirements of these specifications. The proportions of water, cement and saturated surface dry aggregates for the mixture shall be selected from Table 1, unless otherwise specified in the special provisions. To determine the pounds of saturated surface dry aggregate per bag of cement, multiply the factors given under Sand, Gravel, Crushed Stone, or slag by the bulk specific gravities of the aggregates to be used. Batch weights thus determined, shall be corrected to take into account the moisture condition of the aggregates as delivered to the measuring bin. If the aggregates contain more water than required for saturation the weight shall be increased accordingly; if they contain less water than required for saturation the weights shall be decreased accordingly.

(*b*) Mixture A shall be used when the concrete is to be compacted and finished with a standard finishing machine without vibration. Mixture B shall be used when the concrete is to be compacted and finished by vibration and it is desired to maintain the same water-cement ratio as when the standard finishing machine without vibration is used. Mixture C shall be used when the concrete is to be compacted and finished by vibration and where it is desired to maintain the same cement content as when the standard finishing machine is used.

(*c*) The ratio of fine to coarse aggregate may be adjusted, for different gradations within the limits of these specifications, to secure concrete of satisfactory plasticity and workability. During the progress of the work, the total weight of aggregate per bag of cement shall not be changed, except as necessary to compensate for differences in specific gravity, and except when concrete of satisfactory plasticity and workability cannot be made without exceeding the maximum net water content specified; under these latter circumstances the Engineer shall reduce the total weight of aggregate as computed from Table 1, by an amount sufficient to insure that the maximum net water content will not be exceeded. The Contractor shall not receive additional compensation for any extra cement which may be required by such adjustment.

MEASUREMENT AND HANDLING OF MATERIALS

19. Cement, aggregates, water

(*a*) Standard size sacks of cement as packed by the manufacturer shall be considered to weigh 94 lb. net. Bulk cement and cement from fractional sacks shall be weighed.

(*b*) When package cement is used, the cement shall be emptied from the sacks into the batch immediately prior to mixing. When bulk cement is used, satisfactory methods of handling and weighing shall be employed. A separate hopper shall always be so designed and operated that the

TABLE 1—PROPORTIONS BASED ON UNIFORM CEMENT CONTENT

Factors Used for Determining Weights of Saturated Surface-Dry Fine and Coarse Aggregate Per Bag (94 lb.) of Cement

Mixture	Cement Bags per Cubic Yard	Maximum Net Water Content Per Bag of Cement, Gal.	Slump in Inches	Factor (F) x bulk specific gravity = lbs. of saturated surface dry aggregate per Bag of Cement								
				When Gravel Is Used as Coarse Aggregate			When Crushed Stone Is Used as Coarse Aggregate			When Slag Is Used as Coarse Aggregate		
				Sand	Gravel		Sand	Crushed Stone		Sand	Slag	
					Fine Size	Coarse Size		Fine Size	Coarse Size		Fine Size	Coarse Size
				F	F	F	F	F	F	F	F	F
A	6.0	6.0	2–3	66	53	81	75	49	76	79	48	73
B	5.5	6.0	1–1½	66	64	96	75	60	91	79	59	88
C	6.0	5.5	1–1½	60	59	87	68	55	83	71	54	81

NOTE: Using the maximum allowable water content, the weights of Aggregates as determined by the above factors (when multiplied by the appropriate number of bags of cement per cubic yard plus the water and cement will produce a cubic yard of concrete. (If an amount of water less than the maximum is used the weights of aggregates will be adjusted to maintain the same minimum cement content as indicated.

quantity of cement for each batch will be maintained in a separate container so as not to come in direct contact with the aggregates.

(*c*) Aggregates shall be weighed. Each size of aggregate shall be weighed separately.

(*d*) The scales for weighing cement and aggregates shall be accurate within one-half of one per cent throughout the range of use. Operation shall be within a maximum allowable error of one per cent for cement and two per cent for aggregates.

(*e*) Mixing water may be measured by weight or by volume. The water measuring device shall be accurate to ½ of 1 per cent. Operation shall be required to be within a maximum allowable error of 1 per cent. When wash water is used as a portion of the mixing water for succeeding batches it shall be measured according to this requirement.

MIXING

20. Mixing at site or at central mixing plant

(*a*) The concrete shall be mixed in a batch mixer. When a drum mixer is used it shall conform to the requirements of the concrete mixer standards of the Mixer Manufacturers Bureau of the Associated General Contractors of America. If another type of mixer is used it shall be of a type satisfactory to the Engineer. The mixer shall be capable of combining the aggregates, cement and water into a thoroughly mixed and uniform mass within the specified time, and of discharging the mixture without segregation. Each batch of concrete shall be mixed for one minute or more after all materials, exclusive of the mixing water, are in the mixer drum. The batch shall be so charged into the mixer that some water will enter in advance of the cement and aggregate, and will continue to flow for a period which may extend to the end of the first one-third of the specified mixing time. The mixer shall rotate at the rate recommended by its manufacturer. Concrete shall be mixed only in quantities required for current use; any concrete which has set so that it cannot be placed properly shall not be used. Retempering of concrete which has partially set, by mixing with additional water, will not be permitted.

(*b*) The mixer shall be equipped with a suitable charging hopper, water storage, and a water-measuring device controlled from a case which can be kept locked. Controls shall be so arranged that the water can be started only while the mixer is being charged and so as to lock automatically the discharge lever until the batch has been mixed the required time after all materials are in the mixer. The entire contents of the drum shall be discharged after each charge has been mixed the required time. In case of mixing at the site suitable equipment for discharging and spreading

the concrete on the subgrade will be provided. The mixer shall be cleaned at suitable intervals. The pick-up and throw-over blades in the drum shall be replaced when they have lost ten (10) per cent of their depth. The volume of the mixed material per batch shall not exceed the manufacturer's normal rated capacity of the mixer, exclusive of the overload. The manufacturer shall install a plate upon the mixer stating the rated capacity and the recommended revolutions per minute.

21. Ready mixed concrete

Ready mixed concrete shall be mixed and transported in accordance with the current ASTM Specifications for Ready Mixed Concrete (Designation C 94).

HIGH EARLY STRENGTH CONCRETE

22. Methods of production

High early strength concrete shall be produced by one of the following methods, or any combination thereof, as specified in the special provisions.

(*a*) By the use of high-early strength portland cement Type III in lieu of normal portland cement (Type I or Type II).

(*b*) By the use of additional normal portland cement (Type I or Type II) in which case the total amount of cement shall not exceed seven bags of cement per cubic yard of concrete.

(*c*) By the use of calcium chloride as one of the ingredients of the concrete in an amount between one and two pounds of calcium chloride per sack of cement. Calcium chloride may be added either dry or in solution. When used in solution, it is convenient so to proportion the solution that one quart contains one pound of calcium chloride.

High early strength concrete shall meet the requirements of these specifications for portland cement concrete.

SUBGRADE PREPARATION

23. Grading stakes

Grading stakes shall be protected by the Contractor. Stakes which become disturbed shall be reset at the Contractor's expense.

24. Disposal of excavated material

Material removed in excavation shall be used in fills on the job, or otherwise disposed of as provided on the plans or in the special provisions. If excavation is in excess of fill, the excess material shall be disposed of by the Contractor at his expense.

25. Excavation below the subgrade

Where the work is in cut, if the Contractor excavates below the surface of the subgrade shown on the plans, he shall refill with approved material compacted as provided for filling and compaction at his expense.

26. Borrowed material

If filling is in excess of excavation, the contractor shall secure the necessary material from borrow pits indicated on the plans. If no such location is indicated or if the amount in the indicated location is insufficient he shall furnish material satisfactory to the Engineer. Payment shall be made for such material at an agreed-upon price per cubic yard.

27. Removal of sod

Any sod within the limits of the fill shall be completely removed to a depth of at least six inches.

28. Filling and compacting

All fills shall be made in layers not more than 9-in. thick which shall be thoroughly compacted by means of a smooth roller, pneumatic tired roller, or a tamping, or sheepsfoot roller. Smooth rollers shall be self-propelled and weigh not less than six tons nor less than 250 lb. per in. width of tread.

Pneumatic tired rollers shall be towed by mechanical equipment sufficiently powered to maintain an even rolling speed. The roller shall be capable of delivering at least 200 lb. per in. of tire tread, and an internal pressure of 4.5 psi shall be maintained.

Tamping or sheepsfoot rollers shall consist of metal rollers, drums or shells surmounted by metal studs with tamping feet projecting not less than 6 in. from the surface of the roller, drum or shell. The rollers shall be of such weight that the load upon each tooth, when any one row of teeth is supporting the whole weight of the roller, shall not be less than 1,250 lb. Each tamping roller shall consist of two sections and the length of each section shall not be less than four feet.

Inaccessible places, and places where rolling is not practicable on account of possible damage to subsurface structures, shall be thoroughly compacted with mechanical tampers capable of striking a blow equivalent to at least 250 lb. per sq. ft. The dead weight of any mechanical tamper shall be in excess of 40 lb. per sq. ft. of bearing surface. Payment for compacting layers in fills by rolling or tamping shall be included in the contract price per cu. yd. for "Grading."

29. Removal of unsuitable material

Fill material shall not contain trash, brick, broken concrete, tree roots, sod or cinders, and all unsuitable material shall be removed to a depth of at least 18 in. below the finished surface of the subgrade. The Contractor will be paid for this work at the prices bid for grading. and materials used. When unsuitable material is removed from the subgrade the surface shall be brought to the correct elevation with approved material placed and compacted as specified herein. Payment for this work will be made at the contract prices for grading and materials.

30. Removing and grubbing for stumps

Where fills higher than 10 ft. are to be made the ground shall be cleared of all underbrush and trees. Where fills are less than 10 ft. high, all underbrush, trees, tree stumps and saplings shall be grubbed and entirely removed.

31. Solid rock

Solid rock (boulders of one cubic yard or more in content, or ledges in their original bed) shall be removed six inches below grade and shall be paid for at the contract price per cubic yard of solid rock.

32. Sidewalk grading

Sidewalk grading included in the contract shall be done at the same time the roadway is rough graded.

33. Payment for grading

The contract prices for grading shall include the cost of excavating and filling, clearing and grubbing, excavating and removing unsuitable materials as required, shaping the subgrade to the prescribed lines and grades, sloping cuts, intersections and approaches, and rolling or tamping below the subgrade in the case of fills; and in connection with street construction, sloping and filling between the curb and sidewalk pavement, and grading and shaping of sidewalk spaces where shown on the plans. The work shall be estimated to the grades and slopes shown on the plans.

34. Rolling the subgrade

The subgrade shall be prepared by compacting with a self-propelled roller weighing not less than 6 tons. Places inaccessible to the roller shall be compacted with mechanical tampers capable of striking a blow equivalent to at least 250 lb. per sq. ft. The dead weight of any mechanical tamper shall be more than 40 lb. per sq. ft. of bearing surface. If the sub-grade is disturbed after acceptance it shall be reshaped and compacted without additional compensation. Payment for compacting subgrade shall be included in the contract prices for grading.

35. Wetting the subgrade

Concrete shall be placed on a moist subgrade except where subgrade paper is required by the special provisions. The subgrade shall be thoroughly wetted a sufficient time in advance of the placing of the concrete to insure that there will be no puddles or pockets of mud when the concrete is placed. The degree of saturation shall depend upon the characters of materials in the subgrade. The subgrade shall not be allowed to dry out before the concrete is placed.

36. Placing subgrade paper

When specified in the special provisions the subgrade after it has been shaped and compacted, shall be covered with subgrade paper. Adjacent

strips of paper shall lap 4 in. and ends shall lap 12 in. After being placed on the subgrade, the paper shall be kept reasonably intact and shall not be hauled over nor have unnesessary holes punched through it.

37. Testing and correcting subgrade

Immediately prior to placing concrete, the subgrade shall be tested for conformity with the cross section shown on the plans by means of an approved template riding on the side forms. If necessary, material shall be removed or added, as required, to bring all portions of the subgrade to the correct elevation. It shall then be thoroughly compacted and again tested with the template. Concrete shall not be placed on any portion of the subgrade which has not been tested for correct elevation.

FORMS

38. Material, dimensions, setting

Side forms shall be of metal of a cross section approved by the Engineer. The height of the forms shall be equal to the specified edge thickness of the concrete. Building up of forms shall not be permitted. Flexible or curved forms of proper radius shall be used for curves of 100 ft. radius or less. Forms shall be of ample strength, not less than $\frac{7}{32}$ in. thick. They shall be provided with adequate devices for secure setting so that when in place they shall withstand, without visible springing or settlement, the weight, impact and vibration of the finishing machine. In no case shall base width be less than 8 in. for forms 8 in. or more in height. The flange braces must extend outward on the base not less than two-thirds ($\frac{2}{3}$) the height of the form. The forms shall be free from warp, bends, or kinks. Any variation of the top of a form from its true plane when tested with a 10 ft. straight edge shall not be greater than $\frac{1}{8}$ in. in 10 ft. and any variation laterally when tested with a 10 ft. straight edge shall not be greater than $\frac{1}{4}$ in. in 10 ft.

39. Grade and alignment

The alignment and grade elevations of the forms shall be checked and the necessary corrections made by the contractor immediately before placing the concrete. When any form has been disturbed or any subgrade thereunder has become unstable, the form shall be reset and rechecked.

40. Base support

The subgrade under the forms shall be compacted and cut to grade so that the form when set shall be uniformly supported for its entire length and at the specified elevations. Subgrade found to be below established grade at the form line shall be filled to grade in lifts of $\frac{1}{2}$ in. or less for 18 in. on each side of the base of the form and thoroughly re-rolled or

tamped. Imperfections and variations above grade shall be corrected by tamping or by cutting as necessary. In exceptional cases the Engineer may require suitable stakes to be driven to the grade of the bottom of the forms to afford additional firmness.

41. Staking forms

Forms shall be staked with three or more pins for each 10 ft. section. A pin shall be placed adjacent to each side of every joint if required. Form sections shall be tightly joined by a locked joint free from play or movement in any direction.

42. Advanced setting

Where practicable forms shall be set for at least 300 ft. in advance of the point where concrete is being placed. Forms shall remain in place at least 12 hours after the concrete has been placed and shall be cleaned and oiled each time they are used.

INSTALLATION OF JOINTS AND REINFORCEMENT

43. General

(*a*) Longitudinal and transverse joints shall be constructed as shown on the plans.

(*b*) Transverse joints shall be expansion joints, contraction joints, or construction joints. Unless other locations are shown on the plans longitudinal joints shall be along or parallel to the center line of the pavement. Transverse joints shall be at right angles to the center line and shall extend the full width of the pavement. All joints shall be perpendicular to the finished grade of the pavement and, when tested with a 10 ft. metal straight-edge placed at right angles to the joint, the surfaces of adjacent slabs shall not vary from each other by more than $\frac{1}{8}$ in. Joints shall be finished as shown on the plans or as indicated in the special provisions.

(*c*) Especial care shall be taken to finish the subgrade accurately to the required cross-section, at the locations where transverse joints are to be installed. If, for any reason, the subgrade is trimmed too low, or if there are any open spaces beneath the joint, the joint material shall be removed, the subgrade backfilled and firmly tamped, and the joint reset.

(*d*) The edges of the pavement at joints shall be rounded to the radius shown on the plans. The joints shall be continuous from form to form, from joint to joint, or from form to edge of slab, as the case may require. The final horizontal position of transverse joints shall be at right angles to the center-line of the pavement on tangents and radially on curves. Longitudinal joints and reinforcement, except dowels, shall not extend through any transverse joints.

44. Longitudinal joints

(*a*) Tie bars shall be placed across longitudinal joints as shown on the plans. They shall be held in position, by chairs or other supports.

(*b*) Longitudinal "metal strip" joints shall be formed by installing a metal parting strip of the gage, shape and dimensions shown on the plans, to be left permanently in place. The metal strip shall be held securely in place, true to line and grade by suitable steel pins, which may be either channel shaped or round bars, spaced at intervals that average not less than 3 ft. and in no case more than 4 ft. The minimum length of metal strips shall be 10 ft. and adjoining sections shall be securely fastened by lapping and pinning, by means of a slip joint, or other approved method. The Contractor shall furnish an approved gage to ride on the side forms for checking the position of the parting strip before concrete is placed against it.

(*c*) Longitudinal "dummy" joints shall be formed by a groove or cleft in the top of the slab of the dimensions shown on the plans. The groove made in the soft concrete by a suitable tooling device, shall extend vertically downward from the surface to at least one third the depth of slab and shall be true to line. When the joint is of the poured type, the groove, as soon as possible after its completion, shall be cleaned and poured full of approved sealing material. When the joint is of the premolded type, strips of premolded filler shall be inserted in the groove immediately after it is formed.

(*d*) Longitudinal construction joints (i.e. joints between slabs placed separately) shall be formed as shown on the plans or as indicated in the special provisions. In forming these joints the contact edge (or edges) of the previously completed slab (or slabs) shall be painted with a heavy coat of bituminous material before the concrete of the adjacent slab is placed, unless a premolded joint filler is required and used between the slabs. In such cases the joint shall be trimmed and sealed as required for transverse expansion joints.

45. Expansion joints at structures

Expansion joints shall be formed about all structures and features projecting through, into, or against the pavement. Unless otherwise indicated on the plans, such joints shall be not less than ¼ in. thick and shall be of the premolded type.

46. Transverse premolded expansion joints

(*a*) Transverse joints using premolded expansion material shall be formed during the placing of the concrete. The methods of construction shall be such that the joints will extend to the full depth and width of a slab. The finished joint shall be true to the transverse line prescribed with an allowable variation of ¼ in. in the width of one traffic lane.

(*b*) Transverse premolded expansion joints shall be formed by securely staking an approved "installing bar" or installing device perpendicular to the proposed surface of the pavement. The installing bar shall be of substantial metal plate and shall have a length one-half inch less than the required width of the slab and shall be cut to the required depth and crown of the slab. It shall be securely staked in position so that the top edge, unless otherwise provided on the plans, will be uniformly ¼ in. below the pavement surface. The lower edge shall be cut to conform to the prescribed cross-section of the subgrade. The installing bar shall be slotted from the bottom as necessary to permit the installation of the required dowels. Suitable means shall be provided on the bar for facilitating its removal. Header boards, sheet metal holders or other devices used in lieu of the installing bar shall be subject to approval by the Engineer. The joints shall be protected against damage until they are installed in the work. Joints damaged during transportation, or by careless handling, or while in storage shall be replaced or repaired by the Contractor. Repaired joints shall not be used until they have been approved by the Engineer.

(*c*) The designated premolded joint filler shall be appropriately punched to the exact diameter and at the locations of the dowels. It shall be furnished in lengths equal to one-half the designated width of the slab. Where more than one section is used in a joint, they shall be securely laced or clipped together. The premolded joint filler shall be placed on the side of the "installing bar" nearest the mixer. The bottom edge of the filler shall extend downward to or slightly below the bottom of the slab, and the top edge, unless otherwise prescribed, shall be held about one-half inch below the surface of the pavement in order to allow the finishing operations to proceed continuously. The top edge of the filler shall be protected while the concrete is being placed, by a metal channel cap of at least ten gage material, having flanges not less than 1½ in. deep. The installing device may be designed with this cap self-contained.

47. Transverse metal strip joints

Transverse "metal strip" contraction joints shall be formed during the placing of the concrete by installing a metal parting strip to be left in place. This strip shall conform to the requirements for type, gage, shape, and dimensions shown on the plans or indicated in the special provisions and shall be securely staked in place. This strip shall be temporarily capped with a metal channel cap. The dowel assembly and the method of placing it shall be as indicated for transverse expansion joints, except that sleeves or caps on dowels will not be required. Concrete shall be deposited as for transverse expansion joints. After the longitudinal floating has been completed but before the surface is finished the metal cap shall be

removed and the concrete edged, and the joint sealed as required for expansion joints.

48. Transverse weakened plane joints

Transverse joints of the weakened plane or "dummy" type shall be constructed in a manner similar to that provided for dummy joints for longitudinal joints, except that such joints shall be provided with slip dowels or other load transfer devices of the type, size, and arrangement shown on the plans.

49. Transverse construction joints

Unless other prescribed joints occur at the same points, transverse "construction" joints shall be made at the end of each day's run or where interruption of more than 30 min. occurs in the concreting operations and the length of pavement laid from the last joint is more than 10 ft. Tie bars ½ in. in diameter and 3 ft. in length shall be placed at intervals of 2½ ft. across all transverse construction joints.

50. Transverse weakened plane contraction joints in pavement base

Concrete bases shall be provided with expansion and contraction joints as shown on the plans. Unless otherwise shown on the plans contraction joints in bases may be made by forming a cleft or groove in the upper portion of the slab either by installation of subgrade paper, or other approved water-proof material, or by means of an installing bar or device used to form the cleft or groove. The installing bar shall be designed to remain straight and true during operation. The groove shall extend across the full width of the slab in a straight line and shall extend vertically downward from the surface for at least one-half the depth of the slab. The groove shall be formed before the concrete has taken an initial set and in such a manner that the finished concrete base shall not be unduly disturbed. Reinforcement shall not extend across weakened plane joints.

Note: For bases other than those laid monolithicly (such as brick vibrated into fresh concrete) with the surfacing material, it is especially important to reduce the interval between joints by means of closely spaced contraction joints so as to control the amount of joint opening (which may extend through the surface course) due to shrinkage and contraction. Experience indicates that the best results are obtained when the spacing of such joints does not exceed 20 ft. Preferably the spacing should not exceed 15 ft.

51. Load transfer devices

(*a*) Dowel bars or some other approved type of load transfer device shall be placed across all transverse joints in the manner shown on the plans. They shall be placed at the approximate center of the slab depth. Dowel bars shall be held rigidly in horizontal and vertical alignment either by suitable holders to be left permanently in place, or they shall be installed as preassembled units wherein the dowels are held in proper

alignment by spacer bars welded or otherwise firmly secured to the fixed ends of the dowels. A tolerance of one in 36 from correct alignment for each dowel, and one in 48 from any adjacent dowel, will be permitted.

(*b*) Supporting stakes, when used, shall be located near the ends of the dowel bars. They shall not be attached to the spacer bars, nor shall they be placed to support the dowel bars between the spacer bar and the expansion joints. They shall be left permanently in place.

(*c*) The free end of each dowel bar shall be painted with one coat of red lead or basic sulphate blue lead paint at the site of the work. When the paint has dried, the free end of each bar shall be thoroughly coated with heavy oil immediately before it is placed in position. The free end of each bar for expansion joints shall be provided with a close fitting dowel sleeve.

(*d*) When a load transfer device other than a dowel bar is used it shall be of the type, size, and spacing shown on the plans, and shall be installed in a manner meeting the approval of the engineer.

52. Installation of joints

(*a*) If the paving mixer is operated from the shoulder, the joints shall be set immediately after the final testing of the subgrade. If the paving mixer is operated from the subgrade, the joints shall be set immediately after it moves forward, so as to permit as much time as possible for proper installation.

(*b*) The assembled joint shall be put in place on the prepared subgrade. It shall be placed at right angles to the centerline of the pavement. The top of the joint shall be set at the proper distance below the pavement surface and the elevation checked by a properly designed templet. On widened curves, the longitudinal center joint shall be placed so that it will be, as nearly as possible, equidistant from the edges of the slab. The joint shall be set to the required line and grade and shall be securely held in the required position by stakes or an approved installing device or both during the placing and finishing of the concrete. Joints shall be installed so that the concrete pressure will not disturb their alignment. The joints shall be vertical and no joint shall deviate more than one-fourth inch in horizontal alignment either way from a straight line. If joints are constructed in sections, there shall be no offsets between adjacent units. Dowel bars shall be checked for exact position and alignment as soon as the joint is staked in place on the subgrade and the joint shall be tested to determine whether it is firmly supported. Any joint not firmly supported shall be reset.

53. Placing reinforcement

(*a*) Reinforcing steel, when placed in the work, shall be free from

dust, dirt, scale, or other foreign matter, and rust of such degree of development as to impair bond of the steel with the concrete.

(*b*) When bar assemblies are shown on the plans, the reinforcement bars shall be firmly fastened together at all intersections. Adjacent ends shall lap not less than 30 diameters.

(*c*) Where bars are fabricated into mat form by positive welding at all intersections, the lap may be of such length as will permit cross bars to overlap each other by at least 2 in. The same requirements apply to end laps and side laps.

(*d*) Steel fabric sheets shall be lapped and shall clear all edges of the slab, as shown on the plans. Where steel fabric is used, the concrete shall be struck off by means of a template at the indicated depth of the reinforcing below the finished surface of the slab. The fabric reinforcement shall then be placed directly upon the concrete after which the balance of the required concrete shall be placed above it.

(*e*) Where sheets of wire mesh or bar mats are required to be lapped, adjacent sheets or mats shall be tied so as to maintain the required lap during placement of the concrete.

(*f*) If shown on the plans, marginal bars shall be placed on chairs or supports, to insure that the bars will be in correct position after the concrete is placed. They shall be given one coat of red lead or of basic sulphate blue lead paint. At the time the marginal bars are placed, the paint shall be dry and hard. After being placed in position, the marginal bars shall be coated with heavy oil.

(*g*) Displacement of reinforcement during concreting operations shall be prevented.

PLACING AND FINISHING CONCRETE

54. General

(*a*) Concrete shall be distributed to such depth, above grade, that when consolidated and finished, the specified slab thickness will be obtained at all points and the surface will not be below the grade specified for the finished surface at any point.

(*b*) The concrete shall be deposited on the subgrade in such manner as to require as little rehandling as possible. It shall be thoroughly consolidated against and along the faces of the forms. Necessary hand spreading shall be done with shovels, not with rakes. Workmen shall not be allowed to walk in the concrete with boots or shoes covered with earth or other foreign substances.

(*c*) Concrete shall be placed only on subgrade which has been prepared as specified and approved. At all times during operations, at least 300

ft. of subgrade shall have been prepared ahead of the mixer. Concrete shall not be placed on a frozen subgrade. No concrete shall be placed around manholes or other structures until they have been brought to the required grade and alignment.

(*d*) Pavement less than 30 ft. wide may be constructed either to its full width in a single construction operation or in lanes, unless one or the other method is expressly stipulated on the plans. Pavement more than 30 ft. wide shall not be constructed in a single operation. When pavement is constructed in separate lanes, the junction line shall not deviate from the true line shown on the plans by more than ½ in. at any point.

(*e*) Retempering concrete by adding water or by other means will not be permitted.

55. Placing and finishing concrete at joints

(*a*) Concrete shall be deposited on the subgrade as near to the expansion and contraction joints as possible without touching them. It shall then be shoveled against both sides of the joint simultaneously, maintaining equal pressure on both sides. It shall be deposited to a height of approximately two inches more than the depth of the joint, care being taken that it is worked under the load transfer devices. The concrete shall not be dumped from the discharge bucket of the mixer directly upon or against the joints, nor shall it be shoveled or dropped directly on top of the load transfer devices. In placing the concrete, against expansion and contraction joints and in operating a vibrator adjacent to them, workmen shall avoid stepping upon or disturbing in any way the joints or load transfer devices, either before or after they are covered with concrete.

(*b*) The concrete adjacent to the joint shall be compacted with a vibrator inserted in the concrete and worked along the entire length and on both sides of the joint. The vibrator shall not come in contact with the joint, the load transfer devices, or the subgrade. If any of the dowel bars are displaced, they shall be realigned before the finishing machine passes over them.

(*c*) After the concrete has been vibrated, the finishing machine shall be moved forward until the front screed is approximately eight inches from the joint. Segregated coarse aggregate shall be removed from both sides of and off of the joint. The screed shall be lifted and brought directly above the joint, set upon it, and the forward motion of the finishing machine shall be resumed. When the second screed is close enough to permit the excess mortar in front of it to flow over the joint, it shall be lifted and carried over the joint. Thereafter, the finishing machine may be run over the joint without lifting the screeds, provided there is no

segregated coarse aggregate immediately between the joint and the screed or on top of the joint.

(*d*) After the concrete has been placed on both sides of the joint and struck off, the installing bar or channel cap shall be slowly and carefully withdrawn leaving the premolded filler in place. After the installing bar or channel cap is completely withdrawn the concrete shall be carefully spaded and additional freshly mixed concrete worked into any depressions left by the removal of the installing bar. The installing bar shall be cleaned and reoiled prior to each installation of a joint.

Immediately after all finishing operations, including brooming, have been completed and before the concrete has taken its initial set, it shall be edged adjacent to all expansion and contraction joints. Care shall be used to remove any concrete which may be over the premolded joint material. The edging tool shall be so manipulated that a well-defined, continuous radius is produced and a smooth, dense mortar finish obtained. The edging tool shall not be tilted while being manipulated.

After the removal of the side forms, the ends of premolded transverse joints at the edges of the pavement shall be carefully opened for the entire depth of the slab, and in the case of air cushion joints any concrete that has been deposited over the end closure shall be removed, care being taken not to injure the ends of the joint. After the curing period and before the pavement is opened to traffic, premolded joints shall be sealed or topped out, leaving a neat uniform strip of an approved filler material.

56. Finishing methods

(*a*) *Machine finishing.* The concrete as soon as placed shall be struck off and screeded by an approved finishing machine to the crown and cross-section shown on the plans and to an elevation slightly above grade so that when properly consolidated and finished the surface of the pavement will be at the exact grade elevation indicated on the plans and free from porous places.

The finishing machine shall be of the screeding and troweling type, equipped with two independently operated screeds, designed and operated both to strike off and to consolidate. The machine shall go over each area of pavement as many times and at such intervals as is necessary to give the proper compaction and to leave a surface of uniform texture, true to grade and crown. Excessive operation over a given area shall be avoided. The last trip for a given area shall be a continuous run of at least 40 ft. The tops of the forms shall be kept clean by an effective device attached to the machine and the travel of the machine on the forms shall be maintained true without lift, wobbling, or other variation tending to affect the precision of finish. The finishing machine shall

be of ample strength to withstand severe use and shall be fully and accurately adjustable for loss of crown or other derangement due to wear.

During the first pass of the finishing machine a uniform ridge of concrete at least 3 in. deep shall be maintained ahead of the front screed for its entire length. Except when making a construction joint, the finishing machine shall not be operated beyond that point where the above described surplus can be maintained ahead of the front screed.

(*b*) *Hand finishing.* Where hand finishing is permitted the concrete shall be struck off and consolidated by means of a metal shod screed to the crown and cross-section shown on the plane and to such an elevation above grade that when consolidated and finished, the surface of the pavement will be at the required elevation. The screed shall be moved forward with a combined longitudinal and transverse motion, moving always in the direction in which the work is progressing and so manipulated that neither end is raised from the side forms during the strike-off process.

(*c*) *Vibrated finishing.* When vibrated finishing is required, by the special provisions, the finishing machine shall be equipped for applying high frequency vibration to the upper surface of the concrete in accordance with the requirements for either of the following types. The particular type selected by the contractor shall be subject to approval of the Engineer. The vibratory units shall be synchronized and shall operate at a frequency of not less than 3,500 cycles per minute.

1. Vibrating units mounted directly on the screeds. This type shall consist of two independently operated screeds. The front screed shall be equipped with not less than one vibrating unit for each 7½ ft. length or portion thereof of vibratory screed. The front screed shall be not less than 15 in. wide and shall be equipped with a bull-nose front edge having a radius of not less than 2 in.

2. Vibrating pan mounted independently of the screeds. This type shall consist of two independently operated screeds together with an independently operated vibratory pan (or pans). The pan shall be mounted in such a manner as not to come in contact with the forms. It shall rest directly on the concrete and shall be so adjusted as to produce uniform vibration over the entire width of pavement surface. The pan shall be equipped with not less than one unit for each 7½ feet of length or portion thereof of vibrating pan. The screeds shall be capable of operating in a position that will strike off the concrete at a sufficient height above the top of the forms to allow for proper compaction with the vibratory pan.

3. Internal vibrators. Internal vibrators may be approved for use with the standard finishing machines if specified in the special provisions.

(*d*) *Floating.* As soon as possible, after the concrete has been struck off and consolidated, it shall be further smoothed and consolidated by means of a longitudinal float of a suitable design approved by the Engineer. In this operation the longitudinal float shall be worked with a sawing motion, while held in a floating position parallel to the road centerline and passed gradually from one side of the pavement to the other. Movements ahead along the centerline of the road shall be in successive advances of not more than one-half the length of the float.

(*e*) *Straightedging.* After the longitudinal floating has been completed and the excess water removed, but while the concrete is still plastic, the slab surface shall be tested for trueness with a 10 ft. straightedge swung from handles 3 ft. longer than one-half the width of the slab. The straightedge shall be held in successive positions parallel to the road centerline in contact with the surface and the whole area gone over from one side of the slab to the other. Advance along the road shall be in successive stages of not more than one-half length of the straightedge. Any depressions found shall be filled immediately with freshly mixed concrete, struck off, consolidated and refinished. High areas shall be cut down and refinished. The straightedge testing and refloating shall continue until the entire surface is found to be free from observable departures from the straightedge and the slab has the required grade and crown.

(*f*) *Belting.* After straightedging when most of the water sheen has disappeared and just before the concrete becomes non-plastic, the surface shall be belted with a two-ply canvas belt not less than 8 in. wide and at least 3 ft. longer than the width of the slab, or with an approved wooden belt. Hand belts shall have suitable handles to permit controlled uniform manipulation. The belt shall be operated with short strokes transverse to the road centerline and with a rapid advance parallel to the centerline.

(*g*) *Brooming.* As soon after belting and after the surplus water has risen to the surface, the pavement shall be given a broom finish with an approved steel or fiber broom, not less than 18 in. wide. The broom shall be pulled gently over the surface of the pavement from edge to edge. Adjacent strokes shall be slightly overlapped. Brooming shall be perpendicular to the center line of the pavement and so executed that the corrugations thus produced will be uniform in character and width, and not more than $\frac{1}{8}$ in. deep. The broomed surface shall be free from porous spots, irregularities, depressions and small pockets or rough spots such as may be caused by accidentally disturbing particles of coarse aggregate, embodied near the surface. Brooming will not be required for concrete bases.

(*h*) *Edging.* After belting and brooming have been completed, but before the concrete has taken its initial set, the edges of the slab shall be carefully finished with an edger of the radius required by the plans.

(*i*) *Final surface test.* The contractor will be held responsible for the correct alignment, grade, and contour specified. Any spots higher than ⅛ in. for concrete pavements and ¼ in. for concrete bases and not higher than ¼ in. above the correct surface as shown by the 10 ft. straightedge shall be ground to the required cross-section by the contractor at his own expense. Where deviation from the required cross-section exceeds ¼ in. for pavements or ⅜ in. for bases, the surface shall be removed and replaced by the contractor at his own expense.

57. Cold weather concreting

(*a*) Except by specific written authorization, concrete placing shall cease when the descending air temperature in the shade and away from artificial heat falls below 40 F. It shall not be resumed until the ascending air temperature in the shade and away from artificial heat rises to 35 F.

(*b*) When concreting is permitted during cold weather the temperature of the mixed concrete shall be not less than 60 F. nor more than 100 F. at the time of placing in the forms. The aggregates or water or both may be heated. The aggregates may be heated by steam or dry heat prior to being placed in the mixer. The water shall not be hotter than 175 F.; aggregates shall not be used which are hotter than 150 F.

(*c*) When concrete is being placed during cold weather and the air temperature may be expected to drop below 35 F., a supply of straw, hay grass or other suitable blanketing material shall be provided along the line of the work. At any time when the air temperature may be expected to reach the freezing point during the day or night the material so provided shall be spread over the concrete to a sufficient depth to prevent freezing of the concrete. Such protection shall be maintained for at least five days. If required by the Engineer, concrete less than 24 hours old shall also be covered by approved canvas or similar enclosures and devices capable of maintaining the temperature within the concrete at 50 F. or higher. Concrete injured by frost action shall be removed and replaced at the Contractor's expense.

58. Lighting conditions

When the natural light is insufficient for proper work, operations shall cease unless approved artificial lighting is provided.

CURING

59. Preliminary curing period

The concrete shall be covered with two thicknesses of wet burlap weighing not less than 7 oz. per sq. yd., cotton mats, or other approved material of highly absorptive quality, immediately after final finishing of the pavement surface. The material shall be kept saturated by spraying and shall remain in place for at least 12 hours.

60. Final curing

(*a*) For completion of the curing the burlap. cotton or other mats may be left in place and kept saturated for 72 hours, or they may be removed at the end of the preliminary curing period and the concrete surface protected by keeping the surface covered with water (ponding) for three days after placing of the concrete; or by a one-inch layer of thoroughly wet earth, or sand, or a six inch layer of thoroughly wet straw, hay or similar material maintained on the surface of the concrete and kept thoroughly wet for three days after placing of the concrete. Other methods of final curing may be used if approved by the Engineer. The sides of concrete slabs exposed by the removal of forms shall be protected immediately after the removal of the forms in such a manner as to provide these surfaces with a curing treatment equivalent to that provided by the method prescribed for the surface.

(*b*) Forms shall not be removed from freshly placed concrete until it has set for at least 12 hours.

REQUIRED THICKNESS

61. Pavement thickness

(*a*) The thickness of the pavement shall be determined by measuring the lengths of drilled concrete cores according to the procedure of the current ASTM Tentative Method C-174-42T. At such points as the Engineer may select, in each 1,000 lin. ft. of pavement, two or more cores shall be taken and measured. The average thickness of each mile of slab, or fractional mile, will be determined from these measurements.

(*b*) Pavement of which the average thickness is within $\frac{1}{8}$ in. of the thickness required by the typical cross-section shown on the plans, will be accepted and paid for at the contract price.

(*c*) For pavement, the average thickness of which is less than the thickness shown on the plans by more than $\frac{1}{8}$ in. but by less than $\frac{1}{2}$ in., an adjusted unit price shall be used in payment. This price shall bear the same ratio to the contract unit price as the square of the average thickness of the slab bears to the square of the thickness specified on the plans.

(*d*) Payment will not be made for pavement which is found deficient in thickness by ½ in. or more. Such pavement shall be removed and replaced by the contractor with pavement of the specified thickness at his expense. When the measurement of any core indicates that the slab is deficient in thickness by ½ in. or more, determination shall be made of the thickness of transverse sections of the slab at 25 ft. intervals set off along the center line of the road in each direction from the affected location until a transverse section of the slab is found which is not deficient in thickness by as much as ½ in. The area of pavement for which no payment will be made shall be the product of the width of pavement multiplied by the distance along the centerline of the road between the transverse sections found not deficient in thickness by as much as ½ in. If the Contractor is not satisfied he may request additional cores and measurements. Such measurement shall be made at intervals of not less than 200 ft. The cost of additional cores and measurements shall be deducted from any sums due the Contractor unless the measurements indicate that the slab within the area in question is of specified thickness.

(*e*) No additional payment over the unit contract price bid will be made for pavement found to be thicker than the specified amount.

62. Protection of finished pavement

(*a*) The Contractor shall erect and maintain suitable barricades and, when required in the special provisions, shall employ watchmen to exclude traffic from the newly constructed pavement until open for use. These barriers shall be so arranged as not to interfere with public traffic on any lane intended to be kept open, and necessary signs and lights shall be maintained by the Contractor clearly indicating any lanes open to the public. Where, as shown on the plans or indicated in the special provisions, it is necessary to provide for traffic across the pavement, the Contractor shall at his expense construct suitable and substantial crossings to bridge over the concrete.

(*b*) Any part of the pavement damaged by traffic or other causes prior to its final acceptance shall be repaired or replaced by and at the expense of the contractor in a manner satisfactory to the Engineer. The Contractor shall protect the pavement against both public traffic and traffic of his employees and agents.

63. Public use of thoroughfare

(*a*) Normal, unimpeded use of the thoroughfare of which the proposed pavement is to be a unit, is of value to the public. It is, therefore, mutually understood, that for the sections of the thoroughfare identified on the plans as requiring special traffic handling and for the distances

stated thereon, surfaced road lanes as indicated shall be made available by the Contractor for unimpeded public traffic at all times, and maintained in proper condition throughout the construction period. These lanes shall be of the clear widths stated on the plans, and shall be kept entirely free from encroachment by equipment of the Contractor, by workmen or employees of the Contractor or by storage or transportation of materials intended for the work.

(*b*) The scheme and sequence of construction of the several lanes, slabs and sections of pavement, including the sequence of the shifting of public lanes during progress of construction, shall be as given on the plans or as described in the special provisions.

(*c*) Where the edge of any stipulated public traffic lane is contiguous to an edge of the slab or lane being placed, the Contractor shall provide, erect and subsequently remove, a substantial temporary guard fence, as shown on the plans along the prescribed dividing line, which shall be maintained there until the slab is opened to traffic. The Contractor's plan of operation shall be such as to obviate any need for encroachment on the public traffic lane or lanes. Where so shown on the plans special lanes for the Contractor's trucks and similar vehicles shall be provided, separate from and not interfering with the prescribed traffic lanes. Where the clearance between public traffic lanes and the Contractor's operating equipment is restricted, special delivering equipment may be necessary, designed to deliver and depart within the width of the slab actually being placed without encroaching any public lane.

(*d*) Except where a special bid price for "traffic handling" is required in the proposal and in the special provisions, all cost of handling and protecting traffic, of special equipment, of temporary road surfacing and its maintenance, of temporary guard fences and of other things to be provided or to be done under this paragraph, shall be at the expense of the Contractor.

64. Opening to traffic

Traffic will ordinarily be excluded from the newly constructed pavement for 14 days after the concrete is placed and may be excluded for a longer period if cross-bending tests indicate its advisability. Cross-bending test specimens, prepared at regular intervals from the concrete as it comes from the mixer and cured under the same temperature, moisture and climatic conditions as the corresponding slabs of pavement, shall be employed as a means of fixing the time of opening the pavement to traffic. These beams shall be made and tested in accordance with Section 13. When tests of these specimens indicate that the corresponding pavement has attained a modulus of rupture of at least 450 psi. the pavement shall be cleaned, the joints filled and trimmed and the pavement

opened to traffic. If this strength is not attained within 14 days, the Engineer may open the pavement to traffic at his discretion. The joint or line of separation between adjacent strips or slabs of concrete, when the pavement is constructed in strips or slabs shall be cleaned and filled with an approved sealing material.

The foregoing report is scheduled for presentation at the 40th Annual ACI Convention (Feb. 29-Mar. 2, 1944) on a motion for adoption as an ACI Standard. Written discussion for convention consideration should be available to the ACI Secretary by Feb. 10 and the discussion period closes March 10, 1944 for publication in the ACI JOURNAL for June.

A part of PROCEEDINGS OF THE AMERICAN CONCRETE INSTITUTE Vol. 40

JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

7400 SECOND BOULEVARD, DETROIT 2, MICHIGAN (Supplement) November 1944

Discussion of Report of Committee 617:

Proposed Specifications for Concrete Pavements and Bases*

By C. W. BRITZIUS, GEORGE W. WHITESIDES, R. E. MADISON and Chairman H. F. CLEMMER

By C. W. BRITZIUS†

Having studied the report by Committee 617, it seems to me that under Section 17a that the mix should be designed using the cement that will be used on the project and not as now required that the cement be used that produces the lowest strength of any cement acceptable which is available for the job. We know that different cements will produce different strengths and using a fixed cement content for various brands would result in an acceptable strength for the lowest brand but the best brand would be over strength.

Under Section 17c, I believe the cement content of five sacks per yard is too low. We have done a lot of inspection for airport projects in which our work included design of concrete mixes and in no case could we get down as low as five sacks when designing for a 700 lb. modulus of rupture which is nearly equivalent to your 14 day requirement of 550 lb. I believe the cement content should be six sacks.

Under Section 17d, I believe the procedure for the establishment of the mix to be used should be for the contractor to inform the engineers as to the source of his cement with aggregate and then the concrete mix be designed in the laboratory to meet the specifications. It is only when highway departments are the engineers that the concrete mixes can be established in advance for a great number of sources of aggregate in combinations of fine and coarse aggregates. A great many jobs are airport or city paving projects on which data are not available. I believe the contractor should base his bid on a fixed cement content which I recommend in this case to be six sacks per yard and that owners will

*ACI JOURNAL, Nov. 1943; *Proceedings* V. 40, p. 117. The report was presented March 1, 1944 to the 40th Annual convention and adopted as an ACI Standard, and ratified by letter ballot July 28, 1944 after editorial revisions by the committee as noted p. 144-5.

†Twin City Testing & Engineering Laboratory, Inc., St. Paul 4, Minn. Discussion by letter to the Committee, Jan. 22, 1944.

pay for cement used in excess of that amount or receive a credit if less than that amount is used.

I question the value of Section 18 and Table 1.

In Section 2, "Subgrade Preparations", I believe there should be a requirement included that the measurement of the quality of the compaction be based upon comparison with the standard or modified proctor. This requirement is now standard in soils compaction work. A requirement of 95 per cent modified proctor or 100 per cent standard proctor content should be specified.

By GEORGE W. WHITESIDES*

Commenting on the proposed Specifications for Concrete Pavements and Bases, I should like to point out that the specifications on preliminary and final curing of concrete slab, discussed on page 141, articles 59 and 60, would eliminate the use of membrane curing compounds for the following reasons:

1) Preliminary wet curing, as specified, followed by membrane curing, generally fails to achieve optimum curing, since at the end of the preliminary wet curing, the concrete is never saturated, and in the subsequent application, the curing compound suffers from absorption by the concrete surface.

2) The cost of membrane curing is prohibitive, if it must be preceded by wet curing.

Basically, the primary question lies in the acceptance of the membrane curing method itself, and the acknowledgment that the batch contains sufficient water for adequate curing, provided evaporation is minimized. Two pertinent conclusions have been drawn:

1) All the major agencies which had broad experience with membrane curing prior to the war continue to allow its use, nor do they require the preliminary use of water curing, which was primarily designed for subsequent application of wet earth, paper, or straw.

2) Most engineers reluctant to accept membrane curing compounds base their objections on theoretical grounds.

This specification itself clearly illustrates the feeling that concrete must be kept continuously saturated by external water, denying the possibility that integral in the mix itself is sufficient water for adequate curing. In this connection attention is directed to the article by last year's medalist, and to a vast store of field data, to show that, when properly specified, membrane curing has produced concrete of designed strength. The very marked reduction in cracking and surface crazing

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that can be attributed to membrane curing has a probable relation to the points advanced by Mr. Swayze.†

Of the two serious faults of membrane curing one is the problem of the manufacturers, who should design a more satisfactory method of application. The other results from the failure to promulgate a satisfactory specification. It is peculiar that since general use of membrane curing, efficiency, as measured by water retention, has been steadily lowered, despite the former use of materials with much higher efficiencies. The Highway Research Board specifications call for a minimum water retention of 85 per cent by ASTM Designation C-156-40T, despite the fact that products are available having a minimum loss by the same test of 95 per cent and specifications calling for this efficiency have actually been adopted by several state highway commissions.

It is earnestly suggested that time be allotted to discuss membrane curing compounds and their use in this specification without preliminary water curing. There are certainly among the members of the American Concrete Institute a more than adequate number having practical experience with membrane curing to be familiar with the actual, not theoretical, results.

By R. E. MADISON*

We have read with much interest the "Proposed Specifications for Concrete Pavements and Bases." Our particular interest centers around the fact that there is no provision for liquid concrete curing compound as an alternate in the curing process.

As you know, a very considerable amount of liquid concrete curing compound has been used in the past several years. It might be granted that at the outset certain of the early materials used and the methods for accomplishing application left much to be desired. But from study of much technical information at hand and from numerous field observations, it would appear that the idea of using liquid membrane compositions for the purpose of curing is fundamentally sound.

In other words, the outstanding improvements accomplished in the past two years as required by rigid specifications for performance and the insistence on the development of mechanical methods of application indicate not only a wide interest but a wide acceptance of this method of curing.

The cost of this method is very much in line with present demands. In fact with the present step-up in the rate at which concrete pavements

†"Early Concrete Volume Changes and Their Control" by Myron A. Swayze; ACI JOURNAL, Apr. 1942; *Proceedings* V. 38, p. 425.

*Research Department, Truscon Laboratories, Inc., Detroit, Mich. (by letter to the Committee Feb. 14, 1944)

are placed it would appear very disadvantageous to a contractor to figure on enough burlap, cotton mats, sprinkling equipment, etc., and labor for ponding or wet earth covering *actually to accomplish* a seven day cure, when liquid concrete curing compounds of high quality and approved mechanical methods of application are so readily available. To be sure, a stock of burlap can give the impression that adequate provisions have been made for curing, but there are many further operations involved, together with a large labor supervising job in the actual application of water and handling of earth. When the pavement is being laid even at a rate of 1,000 feet per day the inspectors will find it very difficult to assure themselves positively that the operations necessary to wet curing are being carried out on the 2nd and 3rd days to say nothing of the 7th day.

Contrast this with the use of liquid concrete curing compounds to accomplish curing. Machines are available today which are capable of making application at a rate far greater than the most rapid paving rates contemplated. By virtue of this fact and the requirement in the Specifications that application must be made as soon after finishing as the surface water sheen has disappeared, the whole operation of curing will be under the eyes of the inspector constantly; thus providing positive assurance that curing is being carried out.

With respect to cold weather concreting, there is sufficient evidence at hand to require that curing compound be positively included in the specifications when concrete mixed at a temperature between 60 and 100 F. is placed at 40 F. Since the vapor pressure in the warm concrete will be much higher than that of the surrounding air there will be a tendency for the concrete to lose water at a rate considerably in advance of that which would occur if the concrete were mixed at the same temperature as the air. If the evaporation of the water is not stopped the net result will be a very rapid cooling. (Of course, if too much water is lost shrinkage cracks can occur just as in hot weather.) On the other hand if the proper curing compound is applied the concrete will be as much as 10 degrees warmer (depending on placing temperature) than untreated concrete, when the time comes to apply the protective covering of hay or straw. Further, labor relations will be greatly improved with the elimination of handling water and wet burlap at temperatures approximating 40 F.

Quite naturally the selection of the curing compound used must be made on the basis of compliance with specifications. However, recent changes in U. S. Engineer's Specifications and contemplated changes in A. S. T. M. specifications indicate that quality will be maintained at a high level and that constant improvement can be expected.

With the foregoing thoughts we urge that consideration be given to three new paragraphs in the "Proposed Specifications for Concrete

Pavements and Bases":

1. *Under paragraph 10:—Cover Materials for Curing:*

(c) Liquid concrete curing compounds shall conform to the current Highway Research Board Specification for Liquid Concrete Curing Compounds when tested under American Society for Testing Materials Designation: C156-40T.

2. *Under paragraph 57:—Cold Weather Concreting*
as an addition to paragraph (b):

Upon completion of the specified or indicated finishing work and after the disappearance of the surface water sheen, the exposed concrete surfaces shall be coated immediately with curing compound by means of an approved mechanical applicator in sufficient quantity to produce a uniform coverage, not to exceed 200 square feet per gallon on the concrete.

3. Under "Curing" as an alternate to paragraphs 59 and 60:

Upon completion of the specified or indicated finishing work and after the disappearance of the surface water sheen, the exposed concrete surfaces shall be immediately coated with curing compound by means of an approved mechanical applicator in sufficient quantity to produce a uniform coverage, not to exceed 200 square feet per gallon on the concrete.

EDITORIAL REVISIONS

The report has been revised by Committee 617 for clarification as reported on the Letter Ballot mailed in April as follows:

P. 120 Sec. 13: Change paragraph (2) to read

(2) The load shall be applied normal to the loaded surface of the beam and in such a manner as to avoid eccentricity of loading.

p. 140, 2nd paragraph; change to read

(*i*) *Final surface test.* The contractor will be held responsible for the correct alignment, grade, and contour specified. Any spots higher than ⅛ in. and not higher than ¼ in. for concrete pavements and higher than ¼ in. but not higher than ⅜ in. for concrete bases above the correct surface as shown by the 10 ft. straightedge, shall be ground to the required surface by the contractor at his own expense. Where deviation exceeds the foregoing limits the pavement slab shall be removed and replaced by the contractor at his own expense, as directed by the engineer.

p. 141 change center head "Required Thickness" to
"MISCELLANEOUS".

Closure by H. F. CLEMMER, Chairman for the Committee

Many very valuable comments and suggestions have been received from members of the Institute in regard to the report of Committee. The committee has adopted many of these comments and is giving further consideration to some. It is important to consider that these specifications are prepared for general use, that is, so that they may apply under varying conditions which may prevail over the country.

In regard to the suggestions made by Mr. Britzius: if the selection of the cement to be used is directed by the contractor and any cement passing the standard specifications is permitted for use it is important

that the mix should be designed using that cement which may produce the lowest strength concrete. The committee calls attention to the fact that the specifications do permit the use of a fixed cement content and at whatever unit cement content is desired.

In regard to the comments by Messrs. Whitesides and Madison: the specifications permit the use of any method for final curing approved by the Engineer, applied after preliminary wet curing, and this does prohibit the use of liquid curing compounds. Mr. Madison did not present information showing that such preliminary wet curing was not important in order to provide the maximum value that may be obtained from curing.

Attention is called to the fact that the committee is to be maintained and that further consideration will given many of the problems brought to the attention of the committee.

A part of PROCEEDINGS OF THE AMERICAN CONCRETE INSTITUTE Vol. 40

JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

Vol. 15 No. 2 7400 SECOND BOULEVARD, DETROIT 2, MICHIGAN November 1943

Some Properties of Portland Pozzolana Cements*

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SYNOPSIS

An investigation was made of 12 portland pozzolana, (including 2 laboratory blends), 1 natural and 2 standard portland cements. The cements were tested for part, or all, of the following: strengths, resistance to combinations of cycles of freezing, thawing, drying and soaking; also length changes during alternate wetting and drying, resistance to sulfate solutions, linear changes in autoclave tests, and heats of hydration. Chemical analyses were also made.

The commercial portland pozzolana cements showed strengths approximating, and in some cases exceeding, those required by specifications for standard portland cements. Nearly the same linear changes were shown by all the cements in alternate wetting and drying tests. The portland pozzolana cements showed better resistance to a 10 per cent sodium sulfate solution than the portland cements, at 4 weeks, but at later ages the results tended to be the same. The heats of hydration and resistance to cycles of freezing, thawing and drying (65C (150 F)) of the portland pozzolana cements did not compare unfavorably with those of the standard portland cements.

I. INTRODUCTION

An investigation was started in 1934 to furnish information on the properties of commercial portland pozzolana cements. Samples of 10 commercial products were obtained as available over 4 years. Two portland cement-"Santorin Earth" blends prepared in the laboratory, 1 natural and 2 standard portland cements were also included. Data were obtained on strengths, volume changes, heats of hydration and other properties. Chemical analyses were also made of the cements.

The accumulated data of the tests, some of which extended over several years, are given in this report.

*Received by the Institute, July 16, 1943.
†National Bureau of Standards, Washington, D. C.
‡Mr. Jumper, formerly of National Bureau of Standards, and an ACI Member, died in 1940.

TABLE 1—PERCENTAGE OXIDE COMPOSITIONS OF 13 OF THE 15 CEMENTS USED IN THE STUDY

Type of Cement	Commercial Portland Pozzolana										Natural	Portland	
Cement No.	1	2	3	4	5	6	7	8	9	10	13	14	15
SiO_2	28.2	29.8	28.1	28.2	33.3	27.8	31.2	30.8	26.4	27.3	20.2	21.1	21.8
Fe_2O_3	3.7	3.5	(a) .9	3.6	5.3	4.8	5.3	2.2	3.3	1.6	2.2	2.7	5.3
Al_2O_3	8.2	10.6	10.7	6.4	13.3	8.5	7.1	6.6	7.3	7.8	7.9	6.0	4.5
CaO	48.6	50.2	55.6	56.1	39.7	52.2	49.8	54.2	57.5	50.6	58.9	63.0	65.1
MgO	3.5	1.1	2.2	2.8	2.1	1.0	2.0	1.8	1.6	5.8	2.8	3.3	1.0
SO_3	1.8	1.8	.8	1.2	1.9	1.8	1.5	1.5	1.8	1.6	1.8	1.9	1.6
Ign. loss	5.8	2.8	(b)	1.8	2.7	2.1	.8	1.5	(b)	4.3	5.6	2.1	.8
Na_2O					.04	.16	1.61	.54	.22	.26			
K_2O					1.24	1.29	.93	1.08	.98	.78			
Insoluble	16.5	10.2	.3	10.6	35.5	13.9	19.7	14.9	.5	15.2	1.8	.1	.2
Free CaO	.7	.7	.4	.5	.1	.5	.4	1.0	.1	4.7	5.2	1.6	1.5

(a) Also 0.9 per cent FeO. (b) Gained weight. (c) Blank spaces indicate that data were not obtained.

II. DESCRIPTIONS OF CEMENTS

The oxide compositions* of 13 of the 15 cements used in this study are given in Table 1. The analysis of 8 portland cement clinkers, or cements, used by the manufacturers in the portland pozzolana cements are given in Table 2; also included are those of 2 clinkers used in the laboratory blends. The analysis of the "insoluble residue" of 3 cements, the pozzolana in 2 cements, and the "Santorin Earth" are also given in Table 2. Cements 1 to 10, inclusive, were commercial pozzolana, 11 and 12 were laboratory blends, 13 a natural, and 14 and 15, standard portland. Cements 2 and 6 were of the same brand, but cement 6 was received about two years later than 2. Cements 3 and 9 were also of one brand, 9 having been received about two years later than 3. Each of cements 1, 4, 5, 7, 8, 10, 13, 14 and 15 was obtained from a different manufacturer.

Cements 11 and 12 were prepared by grinding together a mixture consisting of 62.2 parts by weight of crushed commercial portland cement clinker, 35.0 parts of "Santorin Earth," a volcanic ash from the Grecian Isle of Santorin, and 2.8 parts of gypsum. A high-early-strength cement clinker was used for preparing cement 11 and a standard clinker (produced at the same plant as cement 15) was used for making cement 12.

Supplementing the data given in Tables 1 and 2, and showing more completely the nature of the commercial portland pozzolana cements is the following information summarized from statements submitted by the manufacturers.

*The cements were analyzed by E. P. Flint.

TABLE 2—PERCENTAGE OXIDE COMPOSITIONS OF PORTLAND CEMENTS OR CLINKERS USED IN THE PORTLAND POZZOLANA CEMENTS, INSOLUBLE RESIDUES OF CEMENTS 4, 5 AND 6, POZZOLANA IN CEMENTS 7 AND 8, AND SANTORIN EARTH

	(a) Cement	Cement	Clinker	Cement	Clinker	Clinker	Clinker	Clinker	Insoluble Residue	Insoluble Residue	Insolulbe Residue	Pozzolana	Pozzolana	Santorin Earth
No. of Portland Pozzolana Cement	1	2	4	6	7	8	11	12	4	5	6	7	8	—
SiO_2	21.0	22.9	22.1	21.7	20.7	21.7	19.5	24.0	72.3	57.1	68.5	65.5	71.2	67.6
Fe_2O_3	2.4	3.8	3.3	4.1	5.8	2.5	2.5	5.6	4.7	8.2	9.5	6.0	3.0	4.8
Al_2O_3	5.5	5.0	6.1	6.7	5.8	6.6	7.0	3.5	13.6	22.2	14.9	13.8	7.7	16.1
CAO	63.0	64.7	64.6	64.4	64.5	65.7	66.2	64.8	1.4	4.7	1.6	6.4	11.6	4.0
MgO	4.2	1.3	3.0	1.3	1.6	2.3	3.3	.4	.9	1.8	2.1	—	1.9	1.4
SO_3	1.8	1.6	—	1.5	.4	.1	.6	.1	—	—	—	—	.2	—
Ign. Loss	1.2	—	.2	—	.3	—	.5	1.0	—	—	—	.3	2.2	—
Insol.	—	—	—	—	—	—	.4	.3	—	—	—	—	69.8	—
Free CaO	—	—	—	—	.9	—	3.1	.1	—	—	—	—	—	—

(a) The compositions of the cements and clinkers except those of the laboratory blends Nos. 11 and 12 and the compositions of the pozzolana in cements 7 and 8 were submitted by the manufacturers and were claimed to approximate only the compositions of the respective materials used in this investigation.

Cement No. 1

Processing of pozzolana: A 1:1 mixture of red over-burden clay and low-grade cement rock was ground to a fineness of 80-85 per cent passing a No. 200 sieve, and the mixture calcined at 980-1090 C. (1800-2000 F.) in a rotary kiln. The hot mixture was put through a hydrator, enough water being added for complete hydration. The hydrated product was mixed with a partially ground cement clinker and gypsum, and then ground finely.

Type of cement clinker: Standard portland.

Amount of pozzolana: 40 per cent.

Remarks: SO_3 content controlled to meet the 2 per cent limit of specifications.

Cement No. 2

Processing of pozzolana: Clays from 2 sources were finely ground together and made into a slurry the composition of which was controlled for SiO_2, Fe_2O_3 and Al_2O_3. The product, containing small amounts of limestone as impurities, was burned in a cement kiln at a temperature of about 830 C. (1530 F.). There was no fusion of the mixture which after cooling was blended with cement clinker and gypsum and then was finely ground.

Type of cement: Moderate-heat-of-hardening portland. (Standard portland, however, is also used in making this cement).

Amount of pozzolana: 30 per cent.

Remarks: The composition of the pozzolana cement was controlled for a certain maximum of CaO, above a certain minimum of SiO_2, and a certain minimum of insoluble residue. The surface area of the cement was between 2500 and 3000 cm^2/g.

Cement No. 3

Processing of pozzolana: Water cooled granulated blast furnace slag was dried before grinding.

Type of cement clinker: Standard portland.

Amount of pozzolana: About 48.5 per cent.

Remarks: Cement 3 was still in experimental stages, the commercial product is represented by cement 9.

Cement No. 4

Processing of pozzolana: Clay was processed by adding it to the red hot clinker discharging from kiln. No temperature was recorded but the clay turned to a light brown color without showing any fusion.

Type of cement clinker: Standard portland produced at that time.

Amount of pozzolana: Slightly below 20 per cent.

Remarks: Experimental cement.

Cement No. 5

Processing of pozzolana: Properly proportioned calcareous and argillaceous materials were vitrified. The resulting product was a mixture of SiO_2 (noncrystalline), $CaO.Al_2O_3.2SiO_2$, $(FeO.MgO)SiO_2$, and minor amounts of alkali compounds. The clinker or slag was interground with portland cement produced at that time.

Type of cement clinker: Not given

Amount of pozzolana: Usually about 50 per cent.

Remarks: Surface area of cement was about 2200-2400 cm^2/g.

Cement No. 6

Same as cement No. 2 except for cement clinker composition (See Table 2).

Cement No. 7

Processing of pozzolana: The pozzolana was made by heat treatment of sand and clay at 980 C. (1800 F.) in a rotary kiln. The pozzolana was interground with the cement clinker and gypsum.

Type of cement clinker: Low-heat-of-hardening portland.

Amount of pozzolana: 25 per cent.

Cement No. 8

Processing of pozzolana: Shale and limestone ground to 4 mesh were calcined in a rotary kiln at 1000-1100 C. (1830-2010 F.). The pozzolana, cement clinker and gypsum were ground together in ball and tube mills.

Type of cement clinker: Standard portland.

Amount of pozzolana. 25 per cent.

Cement No. 9

See report on cement No. 3, noting that No. 9 is the commercial product of this manufacturer.

Cement No. 10

Cement no longer produced and records not available.

III. PREPARATION AND TESTING OF SPECIMENS

1. Strengths

Compressive strengths were obtained on 6 by 12-in. cylinders made of concrete proportioned either 1:6.7 or 1:5.0 by weight. The sieve analyses of the combined Potomac River aggregates, in accumulated percentages retained, were as follows for the two mixes*

*The "fatness" of the portland pozzolana cement pastes permitted the use of laboratory mixes of such low-sand contents.

Mix	Sieve Size									
	1½ In.	1 In.	¾ In.	⅜ In.	No. 4	No. 8	No. 16	No. 30	No. 50	No.100
1 : 6.7	0	17	38	75	75	78	80	83	95	99
1 : 5.0	0	18	40	78	78	80	82	85	96	99

A C/W ratio of 1.59 was used for the 1:6.7 mix as it gave nearly the same percentage flow* as did the selected C/W of 1.88 for the 1:5 mix. The cylinders were stored moist until tested at 7 and 28 days and 1 year.

Compressive strengths were also obtained by standard procedures (Fed. Spec. SS-C-158; A.S.T.M. C109-37T) on 2-in. cubes made of 1:2.75 fine testing sand and 1:3 standard Ottawa sand mixes. The cubes were stored in water until tested at 7, 28, and 90 days and 1 year.

Tensile strengths were obtained on mixes of the same proportions and materials and at the same ages as those in the tests on the cubes.

2. Linear changes during alternate wetting and drying

The specimens used in the wetting and drying tests were made of the two mixes, 1:6.7 and 1:5.0, already described and were 4 by 4 by 30 in. in size. Glass plugs, as reference points for linear measurements, were imbedded in the end faces of the specimens during molding. The bars were removed from the molds at 24 hours and measured for length. A comparator equipped with an Ames micrometer dial (reading to 0.0001 in.) was used, and a stainless steel rod served as a reference standard. Changes in length are referred to the length at 24 hours.

Two specimens of each mix after measurements for lengths at 24 hours were cured for 27 days in the laboratory air which had a temperature of 21 ± 2 C (70 ± 4 F). These specimens are designated as "dry cured." Two specimens, companion to the above, were moist cured at 21 ± 2 C (70 ± 4 F) for 27 days, and are designated as "moist cured." The lengths of the bars were measured at 3, 7, 14, 21 and 28 days. At the age of 28 days the conditions of storage were reversed, that is, the specimens that had been moist cured were transferred to dry air storage and those that had been dry cured were transferred to moist storage. During the following 4 weeks the specimens were measured weekly, and at the end of this 4-week period (age of 8 weeks) storage conditions were again reversed. Reversal of storage conditions was continued at 4-week intervals up to ages of 2 to 6 years, length measurements being taken each time the conditions were changed. During later tests (after 2 to 6 years) the storage period between reversals was increased to 1 year.

*The flows were measured on a 24 in. flow table which was dropped 15 times in 10 sec. through a height of ½ in.

3. Durability in combinations of freezing, thawing, drying, and soaking tests

The specimens for the durability tests were 3- by 6-in. cylinders made of 1:6.7 and 1:5.0 mixes by weight having C/W ratios of 1.59 and 1.88, respectively. Potomac River sand and gravel, the latter having a maximum size of ¾-in., were used. One set of specimens of each concrete was moist cured for 7 days and a second set for 28 days in the damp closet before being put under test.

The cylinders in sets of three were subjected to the following cycles:

1. Freezing and thawing once daily for 6 days then soaking in water at room temperature for 1 day.
2. Freezing and thawing once daily for 3 days, then drying at 65 C. (150 F.) for 3 days, and then soaking in water at room temperature for 1 day.
3. Drying at 65 C. (150 F.) for 3 days and then soaking in water at room temperature for 4 days.

Specimens companion to those used in the above tests were stored continuously in the damp closet. These, together with the specimens used in the drying and soaking tests, were broken in compression at the ages at which specimens first disintegrated in either the freezing-thawing or the freezing-thawing-drying tests.

The freezing-thawing procedure was as follows: The specimens were placed lengthwise in 1-in. deep pans which were then filled with water and stored over night in a chamber maintained at −5 to −15 C. (23 to 5 F.). The following morning the specimens (in the pans) were transferred to a tank containing water at room temperature and left to thaw.

The specimens were considered to have disintegrated when cracking had decreased their mechanical strength to such extent that they could be broken in two by hand. No progressive spalling was manifested by the specimens used in these tests.

4. Resistance to sulfate solutions

Bars of a 1:5 standard Ottawa sand mix, 1 by 1 by 6 in. in size, were used for testing the cements in sulfate solutions. The cement-water ratios of the mixes were adjusted to given normal consistency. The specimens at the age of 7 days (1 day in molds and 6 days in water) were measured for length. Three specimens for each of the cements were immersed in a 10 per cent sodium sulfate solution; and in tests of cements 6 to 10, inclusive, triplicate specimens were also immersed in a 10 per cent magnesium sulfate solution and in a solution containing 5 per cent sodium sulfate and 5 per cent magnesium sulfate. The bars were measured and examined at 4-week intervals and the average expansions reported.

5. Linear changes caused by autoclaving

Specimens were autoclaved at a steam pressure of 295 psi (216 C (420 F)). Concrete bars, 2 by 2 by 10 in. in size, were made of a 1:5

mix by weight using Potomac River sand and gravel of a maximum size ⅜ in. The sieve analysis of the aggregates, in accumulated percentages retained, was as follows:

Sieve Size						
⅜ In.	No. 4	No. 8	No. 16	No. 30	No. 50	No. 100
0	40	46	51	60	89	98

The C/W ratio was 1.75. These specimens (in duplicate) after 24-hours moist curing were measured for length and then autoclaved for 3 hours. Neat cement bars, 1 by 1 by 10 in., were moist cured for 24 hours, measured for length, and then sets of 2 bars each were autoclaved for 1, 3, and 18 hours. One additional set was cured for 6 days in water after removal from the molds and then autoclaved for 3 hours. The details of the general procedure followed in these tests are given in Fed. Spec. SS-C-158A; A.S.T.M. C151-40T.

One bar from each set of the autoclaved neat cement bars after measurement was stored on the roof and the other in the laboratory. These specimens were examined and measured twice a year. The autoclaved concrete bars together with normally cured ones were tested for flexural strength at 48 hours. The specimens were loaded at mid-length, using a span of 9 in. These results and those obtained on 7- and 28-day normally cured specimens are discussed in the section on strengths.

6. Heats of hydration

Heats of hydration at 7 and 28 days were measured by the differential heat of solution method described in Federal Specification SS-C-158 (Sept. 1936).

IV. DISCUSSION OF DATA

1. Strengths

The compressive and tensile strengths of the different specimens, together with the flows, cement-water ratios and normal consistencies of the mixes are given in *Table 3*.

A. Compressive strength—The 1:6.7 concrete in tests of 9 commercial portland pozzolana cements gave strengths which ranged from 1180 to 2380 psi at 7 days, from 2370 to 4340 at 28 days and from 3390 to 5700 at 1 year. The richer concrete, being stronger in approximately correct proportion to its higher C/W ratio, showed similar spreads in the results. The two laboratory blends and the natural cements gave comparatively low strengths in all concrete tests.

The 2 concrete mixes in tests of the 2 portland cements were too harsh and wet for determining representative strengths. Concrete mixes ordi-

TABLE 3—COMPRESSIVE AND TENSILE STRENGTHS IN POUNDS PER SQUARE INCH AND RELATED DATA

Type of Cement:	Commercial Portland Pozzolana										Portland-Pozzolana Lab. Blend		Natural	Portland	
Cement No.:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1:6.7 concrete, C/W = 1.59 (6 by 12 in. cylinders)															
Flow, Per Cent	35	60	61	39		40	45	28	44	29	62	60	45		
7 d.	1430	1250	1440	2380		1620	1820	2360	1180	1820	960	330	1010		
28 d.	2700	2370	2660	4340		2690	2850	3660	2540	2810	1810	760	1740		
1 yr.	3390	4080	4340	4260		4400	3930	5700	5330	3960	3440	2290	3040		
1:5 concrete, C/W = 1.88 (6 by 12 in. cylinders)															
Flow, Per Cent	37	60	63	35			47		49		58	68	46		
7 d.	2230	1820	2110	3320			2600		1650		1370	440	1610		
28 d.	3370	3330	3550	5120			3310		3680		2690	1080	2350		
1 yr.	4680	5040	5100	5150			5200		6800		3950	2880	3890		
1:2.75 Fine Testing Sand Mortar (2 in. cubes)															
C/W	1.88	1.88	1.88	1.88		1.88[a]	1.91[a]	1.82[a]	1.91[a]	1.72[a]	1.88	1.88	1.88	1.88	1.88
Flow, Per Cent	74	104	91	99		99	107	101	100	101	82	105	108	83	95
7 d.	2090	1710	2780	2990		2030	2350	3090	1500	1940	1350	410	1360	2050	2260
28 d.	3180	3250	5780	5620		3210	3370	5210	3230	3030	2140	980	2040	3330	3760
90 d.	3920	4890	6230	5960							3020	2190	2790	3830	4700
1 yr.	4120	5550	7060	5720							4630	3820	3080	3950	5280
1:2.75 Fine Testing Sand Mortar (tensile briquets)															
7 d.	220	225	300	335							180	90		270	295
28 d.	340	320	460	450							315	190		365	450
90 d.	400	440	490	490							390	400		415	470
1 yr.	400	460	490	415							485	490		380	455
1:3 Standard Ottawa Sand Mix (2 in. cubes)															
C/W	2.29	2.43	2.32	2.23	2.27	2.27	2.32	2.19	2.32	2.21	2.29	2.43	2.31	2.40	2.45
Water for Normal C'n'stncy, Per Cent	26.4	23.0	26.0	28.0	26.8	27.0	26.0	29.2	26.0	28.8	26.4	22.8	26.2	23.4	22.4
7 d.	2450	2350	3500	3820	2180	2680	3050	4260	2360	3110	2120	750		2810	3200
28 d.	3840	4290	6210	5710	3230	4440	4020	6420	4730	4420	3340	1670		3860	4970
90 d.	4590	5370	6700	6550	4740						4510	3220		4540	5880
1 yr.	4980	6380	6980	6740	6380						6280	4680		5330	6600
1:3 Standard Ottawa Sand Mortar (tensile briquets)															
7 d.	305	290	340	355	265	350	350	400	270	345	260	125	190	295	300
28 d.	385	410	460	485	380	420	395	515	455	460	365	255	290	395	435
90 d.	410	460	520	510	455						440	425	350	420	550
1 yr.	380	480	550	420	525						515	490	350	365	415

(a) C/W ratios were adjusted so that mixes had nearly the same flows (99 to 107).

narily used with portland cements were not included in the tests, and therefore, no comparison is made between the concrete strengths of the two types of cements.

Notwithstanding the differences in flows for each mix the 1:5.0 concrete and the 1:2.75 mortar, both having the same or nearly same C/W ratio, gave approximately the same strengths at 7 days except for cement 3. At 28 days the differences in strengths between the 2 mixes were slightly larger than at 7 days, and at 1 year the agreement was even poorer than at the other 2 ages. At all ages the mortar made of cement 3 was much stronger than the concrete.

The results on the 1:2.75 mortar show that 7 out of the 9 commercial portland pozzolana cements complied with the 7-day strength requirement of 1800 psi, and all 9 complied with the 28-day strength requirement of 3000 psi (Fed. Spec. SS-C-208 (1938)).

It is to be noted that the strengths of the 1:3 standard Ottawa sand cubes were generally higher than those of the 1:2.75 fine testing sand cubes. However, the variations in differences, particularly at 7 and 28 days, are large.

The flows of the portland pozzolana cement mixes varied over a wide range for each of the two C/W ratios indicating a considerable difference in workability. Actually no great difference was observed in the ease of molding the specimens, all requiring a minimum of tamping, except for cement 3 and the two laboratory blends. These 3 cements yielded harsher and wetter mixes than the others, and probably would have appeared to better advantage had a more plastic mix been used.

B. Tensile strength—The tensile strengths of the 1:3 standard Ottawa sand briquets made of the 10 commercial portland pozzolana cements ranged from 265 to 400 psi at 7 days and from 380 to 515 at 28 days compared to the ranges of 295 to 300 and 395 to 435 for the 2 portland cements at 7 and 28 days, respectively. The natural cement gave comparatively low results at the 4 ages. The strengths of the laboratory blended cements No. 11 and 12, particularly 11, were low at 7 and 28 days, but increased excellently during the later ages. Both portland cements showed a marked retrogression in strength between 90 days and 1 year. This was true of only cement 4 among the 5 portland pozzolana cements tested at these ages.

No correlations were found between the tensile strengths of the mortars made with the two types of sand except that many of the results at both 90 days and 1 year showed good agreement, although, at 7 and 28 days the 1:3 Ottawa sand mortar, as would be expected from the higher C/W ratio, gave higher strengths.

TABLE 4—MODULUS OF RUPTURE IN POUNDS PER SQUARE INCH OF AUTOCLAVED AND NORMALLY CURED 2 by 2 by 10 IN. CONCRETE SPECIMENS HAVING ⅜-IN. MAXIMUM AGGREGATE

		Cement No.				
		6	7	8	9	10
Age Cured	Type of Curing	Modulus of Rupture (psi)				
48 hr.	Autoclave	460	370	680	510	490
48 hr.	Normal	250	330	410	230	260
7 d.	Normal	450	560	580	470	470
28 d.	Normal	610	650	720	660	560

C. Flexural strength—The flexural strengths obtained on cements 6 to 10, inclusive, are given in Table 4. With the exception of cement 7 the strengths of the autoclaved specimens were higher than those of 7-day normally cured specimens, and in all cases were lower than those of 28-day normally cured specimens. In the case of cement 7, autoclaving increased the strength by only a small amount.

2. Linear changes during alternate wetting and drying

All cements except No. 5 and 10 were used in the tests for indicating the effects of alternate wetting and drying on the lengths of concrete specimens. The two concretes, 1:6.7 and 1:5.0, gave nearly the same results. Similarly, the portland pozzolana, the laboratory blended, the natural and the portland cements all yielded about the same results except for cement 3. Accordingly the individual values of representative cements, No. 2, 4, and 15, and the values of cement 3 are the only values reported in detail, and these for the 1:6.7 concrete. These data are presented in Fig. 1 together with the average results of 12 cements (No. 3 excepted) for both concretes and are discussed below.

A. "Moist cured" specimens—The specimens stored moist after removal from the molds at 24 hours showed little or no expansion. The average expansion at 4 weeks was 0.003 per cent (range of 0.000-0.005). The drying of these bars during the interval between 4 and 8 weeks resulted in a progressive shrinkage which averaged 0.024 per cent (range of 0.020-0.028) at 8 weeks. The specimens when stored moist during the next 4 weeks, and also after subsequent 4-week periods of moist storage, did not expand to the 24-hour length. The net shrinkage which averaged 0.005 per cent at 12 weeks increased to 0.009 per cent at 36 weeks and then remained nearly constant at 0.009 per cent (range of 0.005-0.016).

Following the first few repeated wettings and dryings (through 24-32 weeks) the difference between the "moist" and "dry" lengths averaged

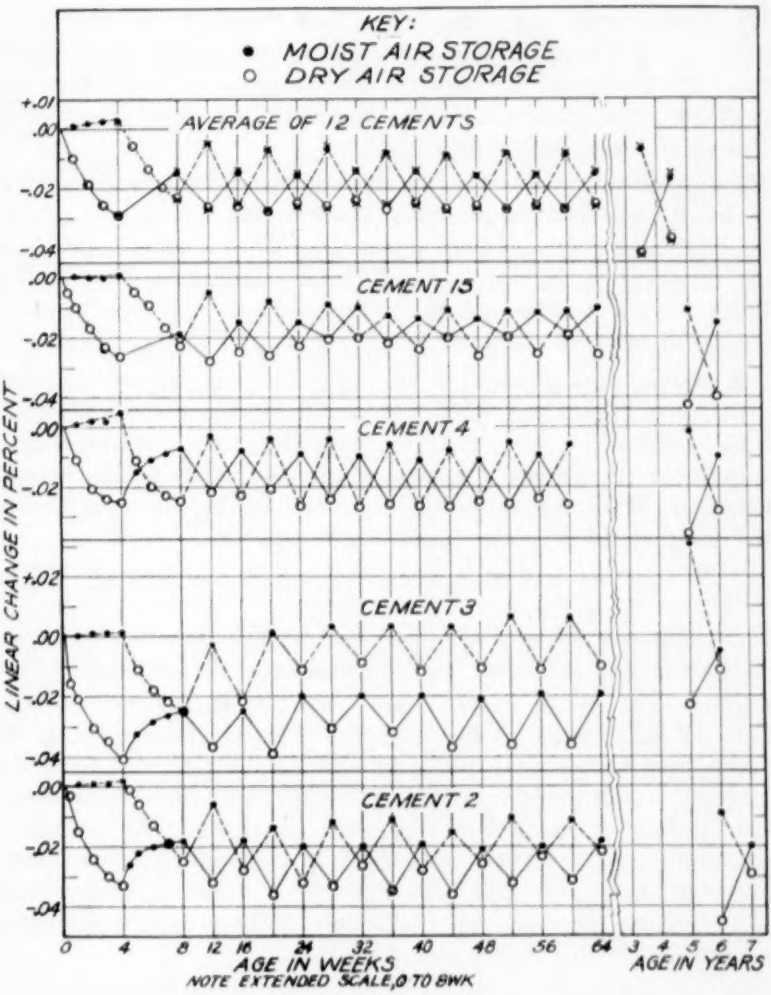

Fig. 1—Percentage linear changes of 1:6.7 concrete specimens stored alternately in dry and moist air. (The average results for 1:5 concrete are designated by X)

0.016 per cent. The values for the individual cements ranged only from .013 to .019 per cent. During the first few reversals the expansions and contractions were slightly higher than 0.016 per cent.

Specimens of cement 3 showed a small but steady growth with repeated wetting and drying.

B. "Dry-cured" Specimens—The specimens placed in the laboratory air after removal from the molds at 24 hours showed shrinkage which at 4 weeks averaged 0.029 per cent (range of 0.025-0.34, except for cement 3

which showed 0.041 per cent.) The bars stored moist after the "dry curing" did not expand to the 24-hour length during the following 4 weeks but showed an average net shrinkage of 0.15 per cent (range of 0.009 to 0.020). The average net shrinkage remained nearly constant at this value for all later measurements.

The differences between the "moist" and "dry" lengths averaged 0.011 per cent after the first few reversals (28-32 weeks). It may be noted that these differences averaged 0.007 per cent for the 2 portland and 1 natural cements, whereas, the portland pozzolana cements showed an average of 0.014 per cent. This was the only consistent variation which these data showed between the portland pozzolana and portland cements.

The average of shrinkages at the end of 4-week drying following the 4-week moist curing was 0.027 per cent. In this respect only do the average results for the "moist"- and "dry-cured" specimens agree. Otherwise the "dry-cured" specimens showed a slightly smaller expansion-contraction differential and a slightly larger net shrinkage after storage in the damp closet than the "moist" cured specimens.

C. Effects of alternate 1-year periods of wetting and drying.—The specimens, except those of cement 3, after the first few alternations showed no further changes of either the "moist" or "dry" lengths for 28-day storage periods totaling 2 to 6 years. For this reason the period between alternations was increased to 1 year. The data for the interval between 64 weeks (the last 4-week value reported in Fig. 1) and the age at which the specimens were stored for 1-year intervals are omitted from Fig. 1. The results at the right side of Fig. 1 show that the lengths after the 1-year periods of "moist" storage were about the same as after the 28-day periods. The lengths after the 1-year periods of drying, however, were substantially less than those observed after the 28-day periods. (The shrinkages averaged approximately 0.040 per cent compared to about 0.025 after the 28-day periods).

Both concretes gave nearly the same results except for cement 3. The 1:5.0 concrete of this cement showed an expansion of 0.020 per cent larger than that of the 1:6.7 concrete.

3. Durability in combinations of freezing, thawing, drying, and soaking tests

The results of the durability tests are given in Table 5. This table shows that neither changing the mix from the 1:6.7 to 1:5.0 nor lengthening the curing period from 7 days to 28 days affected the resistance of the cements to the cycles of freezing, thawing, and drying. Three (No. 5, 12 and 14) of the 8 cements, however, were markedly less resistant for 7 days curing than for 28 in the freezing and thawing cycle. No trend is apparent in the freezing and thawing cycle between the resistance of the portland pozzolana and the portland cements. In the

TABLE 5—NUMBER OF CYCLES IN WHICH 3 by 6-IN. CONCRETE CYLINDERS DISINTEGRATED, AND STRENGTHS OF COMPANION SPECIMENS SUBJECTED TO DRYING AND WETTING, AND OF THOSE STORED IN DAMP CLOSET

Period of Curing in Days	Mix	Freezing-Thawing, No. of Weeks(b) to Disintegrate	Freezing-Thawing-Drying, No. of Weeks(c) to Disintegrate	(a) Drying-Wetting, Strength, psi	Continuous Damp Storage		Freezing-Thawing, No. of Weeks(b) to Disintegrate	Freezing Thawing-Drying, No. of Weeks(c) to Disintegrate	(a) Drying-Wetting, Strength, psi	Continuous Damp Storage	
					Age, Weeks	Compr'sive Strength, psi				Age, Weeks	Compr'sive Strength psi
		Cement 2—Portland Pozzolana					Cement 3—Portland Pozzolana				
7	1:6.7	60	48	3150	49	3980	56	164	2080	57	2820
7	1:5	63	63	4330	64	4670	60	96	2800	61	3470
28	1:6.7	36	36	3020	40	4140	53	160	1740	57	2800
28	1:5	36	63	3870	40	4440	70	126	1870	74	3730
		Cement 4—Portland Pozzolana					Cement 5—Portland Pozzolana				
7	1:6.7	130	230	4500	131	4230	3	26	2240	4	1950
7	1:5	45	200	4520	46	4170	3	26	2470	4	2200
28	1:6.7	58	175	2420	62	3460	115	29	2660	33	2910
28	1:5	42	110	3630	46	4230	130	29	3590	33	3610
		Cement 11—Lab. Blend					Cement 12—Lab. Blend				
7	1:6.7	300	180	2970	181	4020	7	200	1560	8	1550
7	1:5	300	200	3300	201	5100	7	200	2080	8	1980
28	1:6.7	300	170	3720	174	4230	120	180	2730	124	3680
28	1:5	200	170	3290	174	4710	160	200	2580	164	4090
		Cement 14—Standard Portland					Cement 15—Standard Portland				
7	1:6.7	6	11	2030	7	2070	40	10	2510	11	2670
7	1:5	5	7	2710	6	3090	43	16	3330	—	——
28	1:6.7	200	12	2630	16	2900	39	11	2650	15	3300
28	1:5	230	10	3360	14	3400	39	14	4330	18	3980

(a) Tested at the age when specimens first disintegrated in either the freezing-thawing, or the freezing-thawing-drying tests. Specimens stored in damp closet were also tested at that time.
(b) One week consisted of freezing and thawing once daily for 6 days then soaking in water at room temperature for 1 day.
(c) One week consisted of freezing and thawing once daily for 3 days then drying at 65 C (150 F.) for 3 days, and then soaking in water at room temperature for 1 day.

TABLE 6—PERCENTAGE EXPANSIONS OF 1:5 STANDARD OTTAWA SAND MORTAR BARS IN SULFATE SOLUTIONS AND AGES AT WHICH BARS DISINTEGRATED

	10 Per Cent Sodium Sulfate Solution													
Type of Cement:	Commercial Portland Pozzolana										Portland-Pozzolana Lab. Blend		Natural	Portland (Group of 28)
Cement No.:	1	2	3	4	5	6	7	8	9	10	11	12	13	No. of Cements Disintegrated
Age, Weeks														
4	.088	.086	.058	.086	.15	.12 (12)	.042	.024	.036	.10	.11	.036	(4)a	0
12	.30	.12	.18	1.06 (14)	.19		.44	.052	.092	.78 (16)	.19	.032		13
28	.47	.23	.87 (32)		.23		*1.05 (40)	.094 (44)	.25 (40)		.32	.038		17
52	.76 (60)	.54 (60)			.27 (260)						.31 (200)	.036 (b)		20

	10 Per Cent Magnesium Sulfate Solution					5 Per Cent Sodium Sulfate plus 5 Per Cent Magnesium Sulfate Solution				
Cement No.:	6	7	8	9	10	6	7	8	9	10
4	.37 (8)	.070	.44 (8)	.55 (8)	.26	.052	.016	.058	.068	.086
12		.90 (16)			1.36 (20)	.42 (28)	.22	.23	.33	.62 (24)
28							.62	.47 (52)	.85 (36)	
52							.90 (100)			

(a) Numbers in parentheses are the ages in weeks at which bars were found either crumbled or cracked and warped to such extent that measurements could not be made.
(b) Apparently sound at 5 years.

freezing, thawing, and drying cycle, however, the portland pozzolana cements were more resistant. In this comparison though, large variations among the results for the portland pozzolana cements are to be noted. Because of these variations and the small number of portland cements tested no general conclusions can be drawn from these data regarding the relative durability of the 2 types of cements.

A comparison of the compressive strengths of the specimens stored in the damp closet and those subjected to cycles of drying at 65 C (150 F) and soaking show that with the exception indicated below, the strengths were decreased by the drying and soaking treatment (2 to 50 per cent decrease). Specimens of cement 4, 5, 7, both concretes at 7 days and cement 10, richer mix at 28 days, constituted the exceptions. Specimens of cement 3, which showed the largest reduction in strength, were badly cracked.

4. Resistance of mortar specimens to sulfate solutions

The results of the sulfate resistance tests on the cements are given in Table 6. For purposes of comparing the resistances of the portland pozzolana cements to those of portland cements tested in a 10 per cent solution of sodium sulfate there are given in Table 6 the number of portland cements in a group of 28 that disintegrated* at ages of 4, 12, 28 and 52 weeks. At 4 weeks specimens of both types of cements were intact. However, the expansions of the portland cements ranged from 0.050 to 1.85 per cent and those of the portland pozzolana from 0.024 to 0.15 per cent at this age. Also, as a further comparison only 2 of the 10 portland pozzolana cements showed expansion greater than 0.10 per cent whereas, 22 of the 28 portland cements exceeded this value. At later ages, however, the specimens of most of the portland pozzolana cements had expanded considerably (as also did those of the portland cements), and within a period of 1 year, except those of cement 5, had either disintegrated or were nearly disintegrated. Out of the group of 28 portland cements 8 remained intact through a period of 1 year, and 5 of these showed less expansion at 1 year than that shown (0.27 per cent) by the 1 portland pozzolana cement.

The portland cement used for preparing laboratory blend No. 12 showed nearly the same high resistance to sulfate action as the blend itself. The cement used for making the other blend, No. 11, was not tested for sulfate resistance.

The action of the 10 per cent magnesium sulfate solution as shown by results for cements 6 to 10 inclusive, was markedly more severe than that of the 10 per cent sodium sulfate. The combination solution, 5 per cent of sodium sulfate plus 5 per cent magnesium sulfate was slightly

*Unpublished data in this laboratory. Results at 4 weeks and 5 years of similar tests on 102 portland cements were reported by R. Gause (ASTM Bulletin, Oct. 1941).

TABLE 7—PERCENTAGE LINEAR CHANGES OF 1 by 1 by 10-IN. NEAT CEMENT BARS, AND 2 by 2 by 10-IN. CONCRETE SPECIMENS DURING AUTOCLAVING AT 295 PSI, 216 C (420 F.)

Neat Cement Specimens

Age Cured	Time Autoclaved, Hours	Cement No. 6	7	8	9	10
24 hr.	1	+0.009	+0.013	−0.021	−0.017	
24 hr.	3	− .006	+ .003	− .012	− .020	+0.236
24 hr.	18	+ .056	+ .066	+ .068	− .016	
7 d.	3	− .032	− .002	− .030	− .031	+ .215
		Concrete Specimens				
24 hr.	3	+0.046	+0.080	+0.035	+0.017	+0.074

less severe for 3 cements but more severe for 2 cements than the 10 per cent sodium sulfate solution.

5. Linear changes of specimens caused by autoclaving

The results of autoclave tests made on cements 6 to 10, inclusive, are given in Table 7. With the exception of cement 10 the linear changes of the neat cement bars ranged from −0.032 to + 0.068 per cent for all tests. Cement 10 showed expansions of 0.215 and 0.236 per cent. The differences produced by varying the time of autoclaving (1, 3, or 18 hours) or the time of curing (24 hours or 7 days) are not significant from the standpoint of the acceptance limit (1.0 per cent) of the standard test, Federal Specifications E-SS-C-158a. The concrete bars showed expansions ranging from 0.017 to 0.080 per cent. In the case of cement 10 the concrete bars expanded markedly less than did the neat cement bars.

6. Heats of hydration

The heats of hydration, in cal/g, of cements 6 to 10, inclusive, were as follows at 7 and 28 days:

	Cement: 6	7	8	9	10
	cal/g				
7 Days	63	59	79	52	55
28 Days	80	75	96	70	72

With the exception of cement 8 the heats of hydration of these cements meet the requirements, 70 and 80 cal/g at 7 and 28 days, respectively, of the moderate-heat-of-hardening cements (Fed. Spec. SS-C-206a). A comparison of the results for cements 8 and 9 shows a marked difference in the heats evolved within this group of 5 cements.

7. Miscellaneous

The portland pozzolana pastes were generally very sticky compared to those of portland cements. Also, even though the flows were comparatively low, in a number of cases the pozzolana cement mixes were markedly "fatter" than those of the portland cement, permitting easy fabrication of specimens.

The 4- by 4- by 30-in. concrete bars made of cements 1, 2 and 4 showed easily detectable cracks in the first few weeks. However, the cracks disappeared in less than a year.

Some of the autoclaved neat paste specimens after ½ to 4 years' storage on the roof showed extensive cracking and a few were broken by the weathering action. The notations on cracking of the specimens together with their linear changes (referred to the lengths after autoclaving) are given in Table 8. It may be noted that the specimens stored in the laboratory appeared sound up to an age of 3 years, but in the interval between 3 and 4 years some of the specimens developed cracks. Small linear changes only, if any, accompanied the development of these cracks. Whether mortar specimens of the same cements would also crack and disintegrate is unknown.

V. SUMMARY OF RESULTS

1. The commercial portland pozzolana cements tested showed mortar strengths approximating, and in some cases exceeding, those required by specifications for standard portland cements. One natural and 2 portland-Santorin Earth cements gave low strengths, particularly at 7 and 28 days.

2. The expansions and contractions of 9 portland pozzolana cements in alternate wetting and drying tests were similar in extent to those of 1 natural and the 2 standard portland cements. One commercial portland pozzolana cement showed a small but steady growth.

3. Combinations of freezing, thawing, drying (65 C (150 F)) and soaking tests gave a variety of results for 6 portland pozzolana and 2 portland cements. The portland pozzolana cements showed a better resistance than did the portland cements to cycles of freezing, thawing, and drying. No definite difference was manifested in the resistance to cycles of freezing, and thawing without drying. Specimens subjected to alternate drying and soaking generally had lower strengths than those stored in the damp closet.

4. The 10 commercial portland pozzolana cements showed better resistance to the action of a 10 per cent solution of sodium sulfate than the portland cements at 4 weeks. During longer periods of storage, however, the greater number of both types of cements underwent excessive expansion or were disintegrated.

TABLE 8—PERCENTAGE LINEAR CHANGES (SHRINKAGE) OF AUTOCLAVED NEAT CEMENT BARS

Stored in the laboratory and on the roof; and notations on the development of cracks in the specimens

Age Cured	Time Autoclaved	Age at Which Measured	Cement No. 6 Lab.	6 Roof	7 Lab.	7 Roof	8 Lab.	8 Roof	9 Lab.	9 Roof	10 Lab.	10 Roof
24 hr.	1 hr.	6 mo.	−0.037	−0.045	−0.045	−0.033	−0.060	(a)	−.040	−0.039		
"	"	3 yr.	.056	.073	.049	(b)	.054		.070	.059		
"	"	4 yr.	.077(c)	(b)	.053(c)		.057(c)		.093	.071		
24 hr.	3 hr.	6 mo.	.047	.038	.046	.039	.068	(a)	.032	(b)	−0.041	−0.030
"	"	3 yr.	.053	.042	.054	(c)	.061		.058	(c)	.084	.033
"	"	4 yr.	.057	.050	.072(c)	(a)	.074		.082(c)	(c)	.111	.045(c)
24 hr.	18 hr.	6 mo.	.027	.021	.035	.031	.036	.024	.011	.004		
"	"	3 yr.	.050	.005	.048	.033	.033	.026	.017	(b)		
"	"	4 yr.	.071	.020(c)	.073	.044	.044(c)	.026(c)	.027			
7 d.	3 hr	6 mo.	.047	.023	.049	.031	.063	.021	.042	.031	.039	.026
"	"	3 yr.	.050	.051	.052	.026	.064	(a)	.041	.031	.067	.047
"	"	4 yr.	.061	.047(c)	.061(c)	.049(c)	.072		.047(c)	.057	.085(c)	.039(c)

(a) Specimen broken due to "weathering" action.
(b) Specimen broken accidentally.
(c) Specimen has deep cracks.

5. The linear changes of neat cement bars during autoclaving were small for 4 or 5 portland pozzolana cement tested, the fifth showing an intermediate expansion (0.24 per cent).

6. Four of the 5 portland pozzolana cements tested for heats of hydration met the requirements of the moderate-heat-of-hardening cements (Fed. Spec. SS-C-206a), the fifth showed higher heats of hydration.

7. Concrete mixes in which the portland pozzolana cements were used were markedly "fatter" than corresponding mixes containing portland cements.

ACKNOWLEDGMENTS

Appreciation is expressed to the manufacturers for having made available the information on the materials used and the methods followed in the manufacturing of the portland pozzolana cements.

Discussion of this paper should reach the ACI Secretary in triplicate by March 1, 1944, for publication in the JOURNAL for June, 1944

A part of PROCEEDINGS OF THE AMERICAN CONCRETE INSTITUTE Vol. 40

JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

Vol. 15 No. 2 7400 SECOND BOULEVARD, DETROIT 2, MICHIGAN November 1943

Tests of Masonry Cements*

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SYNOPSIS

This paper presents results of tests made on seven masonry cements. Properties reported are: water retention, water repellency, tensile and compressive strength, linear changes due to autoclaving and to three different storage conditions. Strength and linear change properties are reported to five years.

INTRODUCTION

This research project was started five years ago in the Materials Testing Laboratory, at the University of Wisconsin, in order to determine properties of seven masonry cements frequently used in Wisconsin.

Good masonry mortars should be (a) easily placed; (b) durable; (c) strong; (d) constantly attractive. In these tests work was done on the first three items; nothing on the last. Available measures of workability in the laboratory include original flow and water retention. For proper and rapid placement mortars must have an optimum water content which is obtained from flow tests. In addition water retention tests indicate how well a mortar will hold its placeability when used under conditions conducive to rapid reduction in water content. Other factors that affect placeability are usually not readily measured from tests, but may be quickly evaluated by the experienced mason in the field. One measure of the durability of a mortar may be had from strength tests made on specimens aged under exposed conditions. Freedom from excessive volume changes due to delayed chemical action and to changes in moisture and temperature may be regarded as another index of durability. Volume changes are usually evaluated from length changes obtained under various storage conditions such as moist closet, outdoor air or autoclave. Large volume changes may produce high stresses, and in severe cases actual destruction may ensue. Water repellency tests may be used to indicate in a general way the absorption and permeability

*Received by the Institute Oct. 1, 1943.
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characteristics, both of which affect durability. Tensile and compressive strength tests on specimens cured in the conventional manner are made to determine if the mortar may be expected to have satisfactory structural strength when in place. Bond, also important, is often checked by tensile and shear bond tests.

Tensile and compressive strengths were determined at six different ages varying from 7 days to 5 years on 1:2 and 1:3 mortars, by volume. Compression tests were made on 390 two-in. cubes, and tension tests were made on 360 briquets. Linear changes were determined over a five-year period on 1:3, by volume, prisms aged under three different storage conditions: moist closet, under water, and outdoor air. Autoclave expansions were also determined. For this program 54 prisms were made, 1x1x6-in.,with brass lugs inserted in the ends. Repellency tests were made on 36 2-in. cubes, and water retention tests were performed on 1:2 and 1:3 mortars, by volume.

This research project was made possible through the research fund of the Mechanics Department, of the University of Wisconsin, and with the assistance of N.Y.A. student help. The author wishes to thank Prof. M. O. Withey for his helpful suggestions, and L. M. Basford, Philip Dent and others for their aid in carrying out the work.

MATERIALS, MAKING, TESTING

The masonry cements used were all purchased on the open market. The sand used in all tests was a specially graded mixture of quartz and dolomite particles with a fineness modulus of 2.08.

While the two mixes used were chosen on a volume basis, 1:2 and 1:3, the actual proportioning was done by weight. In order to convert from volume proportions to weight proportions, the specific weights of the materials in lb. per cu. ft. were taken as follows: sand—85; Brixment, Aetna, Petoskey, and Carney masonry cements—65; Dewey and Utica—67; and Lehigh—70.

Except for certain changes indicated below, the test procedures followed those recommended in Federal Specification SS-C-181 b. The tensile and compressive specimens were made from mortars with a flow of 65 to 80 per cent, and were moist cured for 28 days, during the first 48 hours in the molds.

At 28 days, half of the specimens were placed out doors and the remaining half were kept in the moist closet until test. In the water retention test the flow after suction was determined after allowing the mortar to age for 15 minutes and then remixing for one minute.

For the autoclave tests the prisms were aged about 53 hours, surface dried, and measured to the nearest 0.0001 in. in a comparator. They were then placed on a rack in the autoclave and subjected to saturated steam at a pressure of 150 psi within one hour. After this pressure had been maintained for 3 hours, it was gradually released within a period of 5 min. The prisms were then removed and immersed in water at 150 F and cooled to room temperature in a period not less than 30 minutes. The prisms were then surface dried and remeasured.

RESULTS OF TESTS

A. Water repellency

The results of these tests are summarized in Table 1 and show that all cements tested easily passed the Federal requirement that the ratio 1-hour absorption to 24-hour absorption be less than 90 per cent. The data also show that generally the 1:3 cubes had greater absorptions than did the comparable 1:2 cubes.

TABLE 1—REPELLENCY TEST RESULTS

Each is the average of 3 results. Flow 100-115 per cent.

Name of Cement	1:2 by Volume			1:3 by Volume		
	Per Cent Absorption After		1-Hr. Absorption / 24-Hr. Absorption Per Cent	Per Cent Absorption After		1-Hr. Absorption / 24-Hr. Absorption Per Cent
	1 Hr.	24 Hr.		1 Hr.	24 Hr.	
Brixment	2.8	5.5	50.9	3.8	7.1	53.6
Lehigh	3.6	11.2	32.1	4.5	9.8	46.0
Dewey	1.9	5.8	32.8	2.6	7.2	36.1
Aetna	4.4	10.9	40.4	5.9	10.5	56.2
Utica	2.7	6.4	42.2	3.3	8.0	41.2
Petoskey	3.7	10.3	35.9	5.4	11.1	48.6

B. Water retention

The ratios of flow after suction to initial flow are shown in Table 2 for the 1:2 and 1:3 mortars, by volume. The data show that the ratios for the 1:2 mixes are higher than those for the comparable 1:3 mixes. The data also indicate that all of the masonry cements except Utica showed satisfactory performance in this test. To produce these mixes of similar consistency, initial flow from 100 to 115 per cent, there was a decided spread in the required water-cement ratio which ranged between 0.46 to 0.59 for the 1:2 mixes, and between 0.58 to 0.73 for the 1:3 mixes.

C. Tensile and compressive strengths

The tensile and compressive strengths of the 1:2 and 1:3 mortars under two curing conditions are given in Table 3 for various ages up to

TABLE 2—WATER RETENTION TEST RESULTS

Each initial flow is the average for two batches, each flow after suction is the average of 4 trials

Name of Cement	Proportions By Weight	Water-Cement Ratio, By Weight	Initial Flow, Per Cent	Flow After Suction, Per Cent	Flow After Suction / Initial Flow Per Cent
	1:2 by Volume				
Brixment	1:2.62	0.59	113	92	81.4
Lehigh	1:2.43	0.51	106	89	84.0
Dewey	1:2.54	0.46	106	84	79.2
Aetna	1:2.62	0.55	100	87	87.0
Utica	1:2.54	0.48	111	73	65.8
Petoskey	1:2.62	0.58	110	93	84.6
	1:3 by Volume				
Brixment	1:3.93	0.73	109	76	69.7
Lehigh	1:3.64	0.66	112	82	73.2
Dewey	1:3.81	0.58	104	69	66.4
Aetna	1:3.93	0.69	109	85	78.0
Utica	1:3.81	0.64	110	68	61.8
Petoskey	1:3.93	0.71	100	71	71.0

and including 5 years. During the five-year period the compressive strength generally showed a continued increase for both methods of curing while the tensile strength usually showed very little change after 90 days. For a given condition the specimens cured in outdoor air generally had better tensile and compressive strengths than did those cured in the moist closet, although the specimens made with Utica masonry cement did not appear to follow this general behavior. Under similar conditions the 1:2 mortars had higher compressive strengths than did the 1:3 mortars and also usually had higher tensile strengths.

D. Length changes under various conditions

Mortar prisms, 1:3 by volume, were subjected to the autoclave test previously described and the following expansions in millionths of an inch per inch were obtained:

Dewey—650, Lehigh—683, Aetna—900,
Petoskey—925, Utica—1300,
Carney—25,500, Brixment—disintegrated.

The high expansions obtained with the Carney and Brixment mortars were probably due to the action of unhydrated material.

The data in Table 4 show the length changes that took place during a five-year period under three different storage conditions. Under moist storage all specimens showed some expansion but only Brixment and

TABLE 3—TENSILE AND COMPRESSIVE STRENGTHS

Each is the average of 3 results. Flow 65-80 per cent.

Name of Cement	Water-Cement Ratio, by Wt.	Tension*—psi						Compression*—psi					
		1:2 by Volume						1:2 by Volume					
		7 Day	28 Day	90 Day	1 Yr.	2 Yr.	5 Yr.	7 Day	28 Day	90 Day	1 Yr.	2 Yr.	5 Yr.
Brixment	0.49	160	265	320	310	310	295	880	1605	2500	3665	3880	4790
				520	570	510	430			2975	3880	3945	4415
Lehigh	0.45	270	340	335	320	320	280	2285	2775	3180	3460	3625	4090
				500	570	525	650			4300	4520	4670	5010
Dewey	0.41	300	365	440	455	460	425	2715	3250	4420	5285	5435	6720
				620	600	600	670			5660	6315	6370	6660
Aetna	0.47	200	245	260	255	250	240	1580	1930	2275	2315	2500	2770
				405	425	410	380			3230	3670	3810	4210
Utica	0.43	230	350	410	515	485	355	995	1810	2680	3475	4175	5460
				360	265	330	355			2890	3575	4100	4815
Petoskey	0.49	220	305	310	285	295	300	1990	2730	3170	3650	3705	4530
				450	490	455	495			4240	4580	4830	5430
		1:3 by Volume						1:3 by Volume					
Brixment	0.62	95	190	265	270	275	255	410	785	1295	1910	1960	2530
				330	340	335	375			1730	2435	2650	3600
Lehigh	0.56	165	210	240	230	240	225	1205	1445	1680	1965	2005	2300
				345	355	350	365			2450	2430	2535	2440
Dewey	0.52	215	250	300	335	360	325	1265	1640	2190	2770	2785	3390
				475	500	520	590			3070	3470	3780	4175
Aetna	0.60	130	155	180	180	200	200	775	980	1150	1250	1315	1765
				275	295	305	280			1760	2010	2165	2580
Utica	0.56	165	260	360	435	445	430	550	1135	1840	2510	2785	3850
				290	285	305	370			1750	2350	2985	3810
Petoskey	0.62	165	210	230	220	270	240	1145	1625	1915	2110	2185	2920
				360	380	370	420			2820	2980	3195	3545
Carney	0.60							535	1240	1825	2400	2775	3480
										2425	2835	3265	4125

*Top line—cured in moist closet. Bottom line—cured out doors.

Carney masonry cements showed a continuous gain in expansion with time. Over a five-year period Carney masonry cement had an expansion of .001 in. per in. Under water storage, Brixment again exhibited a continuous gain in expansion with time. Carney masonry cement was not tested in this program. Under outdoor air storage, all cements

showed an increase in contraction with time up to about ninety days, while changes beyond that time were usually not very great. At five years the contractions varied between 500 and 1000 millionths of an inch per inch. Utica, Brixment, and Petoskey masonry cements had the highest contractions.

TABLE 4—LINEAR CHANGES UNDER VARIOUS CONDITIONS

All mix proportions 1:3, by volume. Flow 65-80 per cent. Each value is the average for two specimens.

Name of Cement	Average Length Change, Millionths of in. per in., at					
	7 Day	28 Day	90 Day	1 Year	2 Year	5 Year
Expanions Due to Moist Storage						
Brixment	40	80	190	270	330	420
Lehigh	30	30	20	40	40	30
Dewey	40	80	80	70	60	60
Aetna	70	80	140	110	100	100
Utica	50	70	110	70	80	80
Petoskey	50	50	80	60	60	80
Carney	40	170	480	440	660	1000
Expansions Due to Water Storage						
Brixment	60	80	220	230	300	480
Lehigh	40	30	30	20	20	40
Dewey	40	30	60	50	40	20
Aetna	30	30	40	40	30	50
Utica	20	30	0	0	0	70
Petoskey	100	60	40	30	20	10
Carney	—	—	—	—	—	—
*Contractions Due to Air Storage**						
Brixment	540	700	800	810	870	830
Lehigh	440	540	620	640	650	640
Dewey	360	360	460	500	540	500
Aetna	530	520	590	720	770	730
Utica	580	870	920	980	1010	1000
Petoskey	240	470	810	790	820	810
Carney	420	400	760	720	670	690

*Specimens moist cured in molds for 2 days, then placed outdoors fully exposed to the weather. Air storage period started during June or July.

CONCLUSIONS

1. The six masonry cements tested exhibited satisfactory water repellency properties.

2. All of the six masonry cements tested, except Utica, had satisfactory water retention properties. The best such properties were obtained with Aetna masonry cement.

3. For both conditions of storage, moist closet and out door air, the compressive strengths of the 1:2 and 1:3 mortars generally increased with age. The tensile strengths of the same mortars increased with age up to approximately 90 days after which changes were usually small.

4. Except for Utica masonry cement, the strengths of the specimens cured outdoors generally were higher than those cured in the moist closet.

5. Mortars made with Carney or Brixment masonry cements showed very high expansions in the autoclave test.

6. Under moist air storage conditions all specimens except those made with Brixment and Carney masonry cements showed very little length change. For the two exceptions the lengths increased with the time. Brixment behaved in a similar manner under water storage, while Carney was not tested under this condition.

7. Under dry air storage conditions all specimens contracted in length, but after 90 days the changes were usually small.

8. For the tests conducted, Aetna, Dewey, Lehigh, and Petoskey masonry cements showed satisfactory performance.

Discussion of this paper should reach the ACI Secretary in triplicate by March 1, 1944, for publication in the JOURNAL for June, 1944

A part of PROCEEDINGS OF THE AMERICAN CONCRETE INSTITUTE Vol. 40

JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

Vol. 15 No. 2 7400 SECOND BOULEVARD, DETROIT 2, MICHIGAN November 1943

Job Problems and Practice

"JPP" is a means toward realizing more fully than in a limited number of longer JOURNAL contributions, the mutuality of ACI Membership effort to do a better concrete job. In JPP many Members may participate in few pages. So, if you have a question, ask it. If an answer is of likely general interest, it will be briefed here (with authorship credit unless the contributor prefers not). But don't wait for a question. If you know of a concrete problem solved—in field, laboratory, factory, or office—or if you are moved to constructive comment or criticism, obey the impulse; jot it down for JPP. Remember these pages are for informal and sometimes tentative fragments—not the "copper-riveted" conclusiveness of formal treatises. "Answers" to questions do not carry ACI authority; they represent the efforts of Members to add their bits to the sum of ACI Member knowledge of concrete "know-how."

Why Broom Pavement Transversely (40-143)

Q—Why are concrete highway surfaces broomed transversely? Was the practice adopted as a result of tests? Why not broom the surface longitudinally?

BY A. A. ANDERSON*

A—There have been many ideas regarding the most satisfactory surface texture for concrete pavement, and since it is possible with this material to obtain almost any desired surface texture, various theories have been tried out, both from the standpoint of securing a skid-resistant surface and also one that, while presenting best light-reflecting surface for night driving, would break up the light rays during the daytime, especially with sunshine following a light rain. One of the most effective means of accomplishing both objectives was the broomed surface, and for this reason it was found most effective to have the broom marks made transversely. Transverse brooming facilitates drainage and for this reason would help to maintain high skid resistance of wet pavement.

Another reason for the brooming was to remove the surface laitance and, of course, as a practical operation it was necessary to do this by transverse brooming. For lateral skid-resistant purposes alone the longitudinal brooming would perhaps be more effective, but that is a close question, and the advantages of the transverse brooming seem to out-

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weigh any advantage longitudinal brooming has for a particular purpose. I believe it has been tried experimentally but has not been used to any extent comparable with that of the transverse brooming.

Life Expectancy of a Sidewalk (40-144)

Q—Will you kindly advise me of the Institute's answer, or answers of members, to the following: What is the life expectancy of—(1) 4-in. unreinforced concrete sidewalks composed of (a) 2500 lb. concrete? (b) 3000 lb. concrete? (2) 7-in. unreinforced concrete roads composed of— (a) 2500 lb. concrete? (b) 3000 lb. concrete?

The 4-in. sidewalks are placed on a compacted subgrade composed of sand and a small percentage of loam. Adjacent areas are 6 in. of loam on subgrade identical except that it is not compacted. Subgrade in some instances is fill and in others, natural soil. The average width of walks is 5 ft., cut into approximate squares by separation plates. Expansion joints composed of ½-in. premolded filler are placed approximately every 40 ft. and at junction of walks with permanent structures.

The 7-in. roads are placed on the same type of compacted subgrade as the walks. They are bounded by granite curbs in some instances, bituminous areas in others and 6 in. of loam in still others. The subgrade will be identical. The roads are provided with transverse contraction or "dummy" joints have a depth of 3-in. every 25 ft. and ½-in. expansion joints every 50 ft.

The concrete is placed in Providence, Rhode Island. Temperature ranges from extremes of −10 to +95 F. This past winter the temperature reached a low of −16 F.

By C. H. SCHOLER*

A—If these sidewalks were made of good aggregate and given normal exposure (with good workmanship) I would expect them to last a good many years. I would not expect the 2500 lb. concrete to offer much less resistance over a period of 25 to 50 years. than the 3000 lb. concrete. I am personally acquainted with sidewalks 35 years old which look as though they might have 35 years of additional service left in them. I am also personally acquainted with sidewalks 5 years of age which are now in need of immediate replacement. It is probable that the concrete placed 5 years ago was somewhat stronger than that placed 35 years ago. How much salt will be placed on these sidewalks and these roads? The old sidewalks and roads were in service many years before they were ever given treatments of calcium or sodium chloride.

Such items as these may have considerable influence on the length of life which a sidewalk or pavement may give, and these are items which our inquirer has left out of his question.

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Cement Dermatitis (40-145)

Q—Does anyone know a reliable preventative or cure for the dermatitis which frequently affects workmen continuously engaged in working with wet concrete? We are now trying an emulsion of vegetable oil (applied over the skin before starting work) as a preventative. Perhaps someone else has in practice proved some method of defense. This skin affection is a common one here in Australia, among concrete workmen, and once it starts, it is very hard to get rid of.

By A. J. R. CURTIS*

A—Dermatitis is no great problem in a cement mill where it is possible to supervise the men. Personal hygiene has more to do with it than anything else. Where a workman finds it easy to take a shower once or twice a day with frequent change of underwear the only precaution necessary is the protection of the hands and forearms of those who handle cement steadily as packers and loaders. An application of mineral oil or a grease or cream of almost any kind will give the skin sufficient protection.

The situation is much more complicated out on construction jobs where the control over the workers' bathing habits is usually practically nil. The most aggravated situation is the one in which workers get inside the forms and walk around on wet concrete without tight boots. This exposes the feet and lower legs to a recurrent swabbing of a caustic solution and the resulting dermatitis in shape of burns is likely to be severe. In such cases there is nothing to be done except to stop the exposure.

Mr. Curtis' comments are supplemented by a PCA (Bureau of Accident Prevention and Insurance) information sheet from which the following is quoted.

Frequently a correspondent will inquire about "cement poisoning." Therefore, we make it clear at the outset that portland cement is not poisonous, and is, in fact, a sterile substance. We then discuss the usual causes of the condition. These are:

(1) Sandpaper effect of cement particles when permitted to rub skin surfaces.

(2) Action of perspiration-cement or water-cement solutions in etching off the protective surface oils, inviting inflammation of the skin surface.

(3) Clogging of the pores with hardened perspiration-cement or water-cement solutions, sealing in poisonous excretions of the pores rather than permitting them to escape.

The treatment suggested is based on two principles: (1) prevention of extended contact of cement particles with skin, and (2) inactivation of the alkali. To reduce primary contact with the skin, the wearing of clothing that is as nearly as possible dust-tight, and the application to exposed skin surfaces of an ointment made according to the following formula are suggested: ¾ lb. Vaseline, ¼ lb. Lanolin, 1 teaspoon Powdered Boric Acid; melt and mix well. Add a few drops of compound tincture of benzoin.

*Asst. to General Manager, Portland Cement Assn., Chicago.

This aids in the mixing process. The powdered boric acid will help keep the mixture sweet.

Sodium hexametaphosphate, (known commercially as Calgon), in a 2 per cent solution, has proven valuable in controlling soap workers' dermatitis by inactivating the alkali. This condition is comparable to that of cement or concrete workers except that the former is far more severe. Dr. A. C. Ivy of the Northwestern University Medical School, who conducted the experiments with soap workers, has endorsed the suggestion that the above chemical may be effective also in dermatitis acquired through contact with cement.

By LOUIS SCHWARTZ*

The hydroscopic properties and the alkaline content of the cement are the chief causes of irritation, although the grains of silica may also contribute. Prevention of dermatitis among workers handling wet concrete consists in the daily change to clean dust-proof work clothes, and compulsory shower baths after work. Those inclined to develop dryness and cracking of the skin should wear leather gloves while working and should rub an ointment consisting of equal parts of lanolin and cold cream into the skin before putting on the gloves and before retiring to sleep.

Protective ointments are not as good for prevention as the measures given above. However, if protective ointments must be used, the water repellent type is preferred. A simple ointment of this type can be made by taking 70 parts of anhydrous lanolin and mixing it with 30 parts of castor oil. A little perfume can be added to disguise the rather unpleasant odor of the mixture.† There are a number of ointments manufactured in this country which correspond closely to the above prescription.

Emulsion Curing Compounds (40-146)

Q—Curing by sprayed-on emulsion seems to be a practice in U. S. A. (inquiry from Australia). Here we have found that these emulsions do not adequately protect concrete, in dry conditions, against losing, by evaporation, so much water that curing by this method falls far short of curing by immersion or sprays. We read in the JOURNAL of June, 1942, of a recipe for a curing compound, but when we tried this here, we failed to achieve any really good results. In a few days in dry air, there was a rapid moisture loss in the treated specimen. (Not so rapid as in untreated specimens, but enough to cause us to find it unsatisfactory to our purpose.) We should like to hear the experience of any members (pipe manufacturers especially) who may have tried the emulsion method.

*Medical Director—Chief, Dermatoses Investigations Section, U. S. Public Health Service, National Institute of Health, Bethesda, Maryland.

†See also "Occupational Diseases of the Skin," by Schwartz and Tulipan, Lea & Febiger, Philadelphia, pages 126 to 130.

By R. F. BLANKS*

A—The emulsion type of curing compound described in the ACI JOURNAL, June, 1942; *Proceedings* V. 38, p. 521, (JPP 38-100) has been used with good success on Bureau of Reclamation work, and laboratory tests show that it meets the Bureau's specifications for performance, which specifications are designed to produce the equivalent of 14-day moist curing. It may be that our inquirer will get satisfactory results with this emulsion if the coated surfaces are kept shaded from direct rays of the sun for at least three days after the concrete is placed, as is the Bureau custom. Other details that are important are (1) to see that formed surfaces are moistened with a light spray of water before application of the emulsion, which should be sprayed on as soon as the surface film of water has lost its sheen, and (2) to see that the first coat (two coats are recommended) of emulsion is applied as quickly as practicable after the forms are removed, or in the case of unformed concrete, as soon as finishing is completed. Where maximum daily temperatures range from 95 to 105 F. and humidity is low, it is advisable to moist cure for 24 hours prior to applying the emulsion. For higher temperatures and low humidity, from two to three days of moist curing should precede application of the emulsion.

By ROY W. CARLSON†

The finding of our correspondent is confirmed by many concrete men in the U. S. A. The consensus of opinion of Committee 612 on Curing of Concrete seems to be that curing by sprayed-on emulsions is not sufficient. The tentative report of this committee (unpublished) requires that the application of curing compounds be preceded by moist curing of a type which supplies moisture. The experience of the writer has been that the several curing compounds investigated by him cannot be guaranteed to maintain sufficient moisture for perfect curing in relatively small slabs, prisms and cylinders when there is no preliminary moist curing. It is possible, however, that the rapid developments in curing compounds may alter this conclusion.

By J. C. PEARSON‡

Our experience has been limited, but we have had an impression from our tests of permeability of coatings for concrete generally that it is nearly or quite impossible to get a continuous seal over a concrete surface due to small voids and pin holes, and this is particularly apt to occur when the surface is not smooth and dense. Therefore, even a coating

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that is unaffected by water, lime or any other compound in a fresh concrete surface cannot perfectly retain the water behind it if it is not continuous. Every pin hole becomes a miniature volcano for steam when the vapor pressure behind it exceeds that of the surrounding atmosphere, and that is really the condition that prevails all the time after the membrane is applied.

A part of PROCEEDINGS OF THE AMERICAN CONCRETE INSTITUTE Vol. 40

JOURNAL
of the
AMERICAN CONCRETE INSTITUTE

Vol. 15 No. 2 7400 SECOND BOULEVARD, DETROIT 2, MICHIGAN November 1943

Current Reviews

of Significant Contributions in Foreign and Domestic Publications, prepared by the Institute's Reviewers

Queens Midtown Tunnel

OLE SINGSTAD. *Proc. Am. Soc. C. E.*, V. 69, No. 3 (Mar. 1943) p. 361-397. Reviewed by H. J. GILKEY

Covers all features of history, design, and construction of this subaqueous highway crossing the East River in New York City. Between portals structure consists of 2 cast iron lined shield-driven tubes 31 ft. in diameter and 3760 ft. long; two structural steel lined tubes in rock tunnel 32 ft. 10 in. in diameter and 1051 ft. long; and steel bent and concrete structures of 387 ft. in Manhattan and 1051 ft. in Queens. Design similar to that of Holland and other modern tunnels for automotive traffic.

Influence and measurement of low temperatures in concrete road construction

WEBER. *Betonstrasse*, 1941, 16 (10), 148-9. *Road Abstracts*, 1943, V. 10, No. 4.
HIGHWAY RESEARCH ABSTRACTS

When concrete construction takes place in cold weather, temperatures should be measured at ground level. Instances are quoted where frost damage occurred although no frost was registered at eye-level. Observations over a period of 33 days in October and November showed differences of 1.8 to 13.3 F. in the lowest temperatures registered at 2 in. and 6.6 ft. above ground level.

Simplified analysis of skewed reinforced concrete frames and arches

RICHARD M. HODGES. *Proc. Am. Soc. C. E.*, V. 69, No. 5 (May 1943), p. 635-663.
Reviewed by H. J. GILKEY

Presents simplified method of analysis for solid-barreled skewed reinforced concrete rigid frames and arches. Assumes that designers know something of theory of elasticity without having made special study of skewed arches. Shows an illustrative design of a grade separation structure of short span but heavy skew. Author believes that there is no justification for avoidance of these types of rigid frame construction on basis of difficulties, delays, or uncertainties in design.

Load test of a slab with all bars lapped

HOMER M. HADLEY. *Civil Engineering*, V. 13, No. 9, Sept. 1943, p. 435. Reviewed by J. R. SHANK

A slab 15 in. wide, 4 in. deep and 9 ft. long was tested on an 8-ft. span in simple bending, by equal loadings 11 in. each side of the mid-span. The reinforcing was five hooked

deformed intermediate new billet ½-in. sq. bars, ½-in. clear coverage. All five bars were lap-spliced close and wired for 20 in. at the mid-span. The strength of the concrete was 4390 psi at 28 days. The test was carried to an easily visible deflection.

The total ultimate load was 9410 lb. which produced a tension in the bars by ordinary calculations of 51,000 psi. and a bond stress of 319 psi. Only the outer two bars showed slippage. Transverse cracks occurred at the bar ends, 11 in. from the mid-span point.

Concrete arch roof for Kansas City factory

TRACY WOOD. *Civil Engineering*, V. 13, No. 8, Aug. 1943, p. 363. Reviewed by J. R. SHANK

A large Pratt and Whitney aircraft engine plant was constructed of reinforced concrete in a very short time as a result of carefully planned design and movable form procedure. The roof was made up of 3-in. thick arches spanning 40 ft. and resting on haunched continuous concrete girders. Segmental diaphragm stiffeners of concrete occurred at the third points of the girder spans.

Girders, arches and stiffeners were poured at the same time. The forms extended to full width of the building excepting for every third or fourth bay where the forms lagged behind one operation to avoid cumulative distortion of the ties at the bottoms of the diaphragms. Forms were lowered simultaneously at a signal and moved ahead simultaneously for another double bay of 80 ft. and jacked into place.

Heating arch ties for concrete roof

FRANK E. STERNS. *Civil Engineering*, V. 13, No. 6, June 1943, p. 253. Reviewed by J. R. SHANK

At St. John, New Brunswick, it became necessary to construct a roof span of some material other than steel. It was decided to make it of reinforced concrete. A tied concrete arch was poured monolithically to columns hinged at the bases. To avoid excessive bending stresses in the columns due to stress elongation of the tie rod and other deformations, the bottom tie rods were pre-elongated by heating them electrically over a portion of their lengths before concreting them into the arch truss, and held to temperature until the concrete of the arch rib had attained sufficient strength to bear its load. The rods were allowed to cool while the truss took on its load thus maintaining constant distance between columns. The operators of this procedure were rewarded for their careful complex calculations by finding that measurements taken after cooling and loading checked their predictions.

Reinforced concrete caisson substructure to a silo

L. E. HUNTER. *Concrete and Constructional Engineering*, V. 38, p. 181-191, June, 1943.
Reviewed by GLENN MURPHY

The author describes the construction of six reinforced concrete caissons and twenty-four footings which formed the foundation for a grain silo. The caissons were rectangular, 16 by 24 ft. in cross section with 4 ft. reinforced concrete walls. A 4-ft. thick horizontal partition 8 ft. above the bottom of each caisson formed the roof of the working chamber. A ¾-in. steel plate 1-ft. wide was attached at the bottom of the walls to form a cutting strip. Each caisson was cast in place with a 3 ft. initial height of wall. As additional weight was needed during sinking, temporary 3 ft. lefts of wall were added. The caissons were sunk approximately 25 ft., about 8 ft. of which was through rock. After the caissons were in place, the working chamber was filled with concrete. A number of the difficulties encountered during the project are discussed.

Rigid-frame concrete industrial plant.

A. F. PLANT and S. J. DEITRICK, *Engineering News-Record*, V. 131, No. 9 (Aug. 26, 1943), p. 76-80.
Reviewed by S. J. CHAMBERLIN

The magnesium-alloying plant required a manufacturing area of 100 x 320 ft. free of columns with a clear height of 30 ft. at the center, an elaborate ventilating system and particularly fire-resistant construction. Concrete rigid frames with precast concrete roof spanning 20-ft. bays were chosen as being the most suitable. The rigid frame legs are 2 x 3½ ft., with 1½-ft. concrete wings on each side which form pilasters that are topped by a concrete cornice. Hollow pre-cast slabs were used to make possible erection in severe winter weather, to eliminate formwork and resulted in appreciable dead load reduction. The roof slabs are securely anchored to concrete frames by plugging the holes in the slabs before making final top casting of the frames. Keyways formed in the roof slabs are grouted to give a splined effect. A concrete catwalk or platform 10 ft. wide is suspended on concrete hangars from the frames for the full length of the building to support ventilating equipment and a monorail. A gravity type continuous ventilator extends 280 ft. along the ridge of the roof and is constructed of pre-cast slabs.

Timber-concrete bridge decks used in Florida

W. E. DEAN. *Civil Engineering*, V. 13, No. 4, Apr. 1943, p. 175. Reviewed by J. R. SHANK

The State Road Department of Florida has designed and built bridges suggested in publications of the Service Bureau of the American Wood Preservers Association. This type of construction is essentially longitudinal planks laid on edge, alternating two different widths, closely in contact for the full width of the bridge, and continuous over supports upon which is placed a reinforced concrete slab wearing surface. Horizontal shear is developed between the concrete and the timber by the concrete in the grooves, usually 2-in. deep, and thin trapezoidal steel plate diaphragms driven across the grooves to embed in the high planks, thus making a timber-concrete composite beam.

In Florida special efforts were made to cut the use of strategic steel to a minimum. The planking was cambered ⅛-in. in 18 ft. by means of timbering before the concrete was placed. Expansion joints were constructed in the concrete over the supports which aided in reducing the region of negative bending and rendering tension in the concrete to practically zero. In seven bridges the only reinforcing was an obsolete type of highway guard fencing. The total weight of metal, per square foot of bridge deck, including shear developers, uplift spikes, and nails between laminations, in accordance with Service Bureau recommendations and reinforcing was approximately 2.00 lb. No cracking of the concrete under traffic has been observed in any of these bridges, the oldest having been finished in February of 1942. The total cost per linear foot of bridge was not different appreciably from that of more conventional types.

Native cane reinforcement in concrete

H. E. GLENN. *Civil Engineering*, V. 13, No. 8, Aug. 1943, p. 386. Reviewed by J. R. SHANK

Cane, native to South Carolina, was found to be of value as reinforcement for reinforced concrete from tests made at the Clemson College Engineering Experiment Station. When large cross-sections of cane (ten or more times as much as would ordinarily be used for steel) were used, large deflections were developed under load while the compressive fiber stresses in the concrete were advanced to failure.

Horizontal shear cracks developed at calculated values of 70 to 80 psi. though the lower covering of concrete did not spall off. Bond stresses because of the large amount of surface were of minor importance though pull-out tests of green cane showed ultimate bond strengths as low as 60 psi.

Properties of the cane were found to be

Tensile strength—25,000 psi (18,000 to 30,000 psi.) net section of shaft
Modulus of elasticity—2,000,000 to 2,500,000 psi.
Bond strength—60 to 140 psi.
Volumetric shrinkage of drying—10 per cent.
Diametric shrinkage of drying—3.2 per cent.

Small variation, whether dry or green, was found for modulus of elasticity. The weakest spot in tension was where the constant diameter part or shaft connected to the joint. The joints served as lugs to improve the bond strength. It was found better to use green cane when pouring because subsequent drying out reduced the diameter very little, the greatest shrinkage being in the inner fibers of the tube serving only to enlarge the inner diameter. When pre-dried cane was used the slight enlargement of the cane due to taking up water from the green concrete split the weak concrete in its early setting period. Split cane was no better in beams than whole cane.

Plain concrete arches

CHARLES S. WHITNEY, *Civil Engineering*, V. 13, No. 1, Jan. 1943, pp. 29-32. Reviewed by J. R. SHANK

Concrete arches usually have fixed ends. The fixed-end arch is statically indeterminate, and the reactions due to loading or volume changes should be determined for the plain arch by means of the theory of elasticity as in the case of the reinforced concrete arch.

Important volume changes are produced by: (1) Dead-load rib shortening; (2) Shrinkage of the concrete; (3) Variations in temperature and moisture content. Shortening of the arch by dead-load thrust is greatly increased by plastic flow occurring gradually over a period of many months. At the same time, plastic flow releases much of the stress and it may be said that in so far as dead-load rib-shortening reactions are concerned the plastic flow can be disregarded. The same modulus of elasticity is used to calculate the amount of shortening and the size of the reactions. Shrinkage and moisture effects are different for different climates and geographical locations. If the arch is cast in sections, plastic flow may be expected to eliminate the effect of the temperature rise due to the heat of setting and of temperature variations during pouring. The arch should be considered fully elastic, E at 4,000,000 psi., for annual temperature variations which may be taken as 60 per cent of the range for the location.

Because concrete is to a considerable degree a plastic material, the straight line stress variation does not well apply. A new formula for ultimate strength is recommended.

$$P = 0.85btf_c\left(1 - 2\frac{e}{t}\right)$$

P = thrust causing failure in lbs.
b = width of section in in.
t = depth of section in in.
f_c = Standard cylinder strength of concrete, psi.

$e = \dfrac{M}{P}$ = eccentricity of thrust, in in. measured from center of section.

It is recommended that the design be such that P is within the limits.

$$P = 0.85btf_c\left(1 - 4\frac{e}{t}\right) \text{ when } \frac{e}{t} < 0.63 \text{ and}$$

$$P = 0.43btf_c\left(1 - 9.8\frac{e}{t}\right) \text{ when } \frac{e}{t} > 0.163 \text{ where}$$

P is the calculated thrust.

The design procedure is very complex. The best proportions can be found only by successive trials. The ordinary procedure of assuming a design and proving by analysis that its strength complies with specification is not sufficient to assure proper proportioning. It is not possible to write a simple equation for proper crown and springing thickness. The volume change moments increase with the thickness of the rib so rapidly as to more than offset the reduction in effect of dead and live loads after a certain thickness is reached.

The plain arch is best suited where dead load is large compared to the live load and where volume change moments are small such as underground structures, large heavy bridges when the rise-span ratio is great, and where the climate is mild and uniform.

The future of the cement industry

P. Malcom Stewart, at annual meeting, Associated Portland Cement Manufacturers, London, July, 1943
Cement & Lime Manufacture, V. 16, No. 8, Aug. 1943, p. 122. Reviewed by J. C. Pearson

Commenting on existing business restrictions, Sir Malcom said that much of the onslaught on monopolies and big business is in effect an attack on organization. When effective organization and rationalization have been rightly applied, they have changed chaos into order and produced a degree of efficiency in industry hitherto unobtained. The attack is thus misdirected. It should be made against the wrongful use of such organization where it is not directed to the welfare of the community. Referring to his own company's performance and policy, Sir Malcom stated that from 1925 to 1938, the cost of production of cement had been reduced 32 per cent and at the same time the selling price had been reduced 34 per cent. This was in the face of advancing costs of steel, fuel and stores, increased wages and improved conditions of work and welfare of employees. Thus better organization and increased efficiency from progressive expansion had benefited both producer and consumer.

The speaker stated that he looked for a sound measure of seasoned reform in post-war industry. He believed that organized control of the cement industry would be even more necessary after the war than before to maintain efficiency, but that some means should be set up for the survey of prices charged to the consumer. He favored a Prices Survey Council with power to survey and check prices and to obtain the relevant data for the purpose. Thus those charging fair prices would secure official approval; others would be required to toe the fair price datum line. With regard to any other controls that might be required, the essential principle to be observed is that these should be designed so as not to interfere with effective executive work and thus impair the maintenance of efficiency. Discussion of the future problems of the industry should not be in terms of State control vs. private enterprise, but on the basis of State control *with* private enterprise.

In regard to the immediate future, a decline in the demand for cement for Government construction is in prospect. There seems no way that this loss of business can be offset until the war is won, and then it will take time for the demand to reach its full strength. A period of adjustment will be needed to give practical effect to the many proposals for reconstruction and planning. As our prospects in the field of conflict become brighter, so the available time for giving effect to principles awaiting determination becomes shorter.

Tensile and other properties of concretes made with various types of cements

Louis Schuman and John Tucker, Jr., Rearach Paper RP 1552, *Journal of Research* of the National Bureau of Standards, V. 31, Aug. 1943. Highway Research Abstracts

(1) An improved tensile-test method for concrete has been developed. Cylindrical specimens, 4 by 16 in. are used, and loads are applied though threaded rods embedded

in a rich mortar at the ends of the specimens. The method gave fairly uniform results because of the greater uniformity of stress distribution over the section of failure than is obtained with grips, or in tapered specimens, etc. (2) Compressive and tensile strengths and some stress-strain relations were determined for concretes made with a number of cements of various types, including five normal, four moderate-heat, and three high-early-strength portland cements, two portland-pozzolans, one high-alumina cement, and nine portland cements with aerating agents. The effects of various sand-gravel ratios and of various coarse aggregates on tensile strength were also studied. (3) The high-early-strength cements gave higher strengths than the normal cements, both in tension and compression, up to 28 days. The moderate-heat cements gave but slightly lower strengths than the normal cements up to 28 days; thereafter there was some tendency for the moderate-heat cements to give higher compressive and tensile strengths than the normal cements. The cements with aerating agents gave somewhat higher tensile strengths than the normal cements up to 7 days, but thereafter both compressive and tensile strengths were lower than those for the normal cements. Of the two portland-pozzolans tested, one gave rather low early strength but came within the range for the normal cements at later ages; the other gave early strengths comparable to a moderate-heat portland but gave relatively low strengths at later ages. The high-alumina cement gave very high strengths at 1 day but showed comparatively little gain at later ages. (4) Tensile strengths usually attained maximum values between 7 days and 3 months, with retrogression in many cases. However, at 1 year, tensile strengths were generally within ±10 per cent of the 28-day strengths, except for the high-alumina cement, which gave appreciably lower values. The fracture sections of the tensile specimens often showed considerable aggregate breakage at 28 days, and somewhat less at later ages. (5) The 1:4.5 mix generally gave higher strengths for all cements than the 1:6 mix at the same age. The use of either a richer mix with the normal cements, or of a high-early-strength cement, was of greater advantage in securing high-early tensile strength than high-early compressive strength. (6) Tensile and compressive strengths show a fair relation, but the 1:4.5 mix gave somewhat higher tensile strengths for equal compressive strengths than the 1:6mix. For compressive strengths up to about 2,500 psi., the 1:6 aerated concretes gave somewhat higher tensile strengths for equal compressive strengths than the 1:6 mix with normal cements. The high-alumina cement gave appreciably lower tensile strengths for equal compressive strengths than the other cements. (7) For the nine aerated 1:6 concretes tested with Potomac River sand and gravel, the weights per cubic foot ranged from 138 to 144 lb. compared with 146 for a corresponding normal cement concrete. Initial tangent moduli of elasticity for the aerated concretes ranged from 3.4 to 3.9 x 10^6 psi. in compression, and from 3.3 to 3.8 x 10^6 psi. in tension, compared with 4.1 and 4.0, respectively, for a normal cement concrete. Both the tensile and compressive moduli increased with compressive strengths, which ranged from 3,100 to 4,600 psi. at 28 days. (8) Tensile strengths of concrete varied considerably with the sand-gravel ratio or with the type of coarse aggregate used. A range of 1.4 to 1 in tensile strength at 28 days was noted for different coarse aggregates, such as slag, crushed stones, and gravel. A crushed limestone gave relatively low tensile strength in a 1:6.4 mix, and rather high strength in a 1:4.8 mix. The article also contains 11 references.

Bulletins on war time road problems

Highway Research Board*

Reviewed by FRED BURGGRAF

There are two major wartime road responsibilities; to keep the traffic essential to the war effort moving, and to bring the existing roads through the war period in as good

*Bulletins No. 1, 2, 3, 4 and 6 are 10 cents each, No. 7, 20 cents and No. 5, 25 cents. Highway Research Board, 2101 Constitution Avenue N. W., Washington 25, D. C.

condition as possible. Discharge of these responsibilities entails consideration of many new factors in view of the limitations on time, money, labor, equipment and use of critical materials imposed by the exigencies of the national situation. Obviously changing emphasis from devising better and more economical methods to a program within the wartime limitations of moving the wartime traffic and conserving the existing roads confronts highway engineers with many new problems and new aspects of old problems.

The Highway Research Board believing that it could be helpful by aiding in disseminating in usable form the best available information on those phases of highway technology in which common practice has not become established or in which practice must be modified during the war, has published, to date, seven bulletins on Wartime Road Problems. These publications have been prepared by qualified committees and the following is a brief review of their contents:

No. 1. Curing Concrete Pavements Under Wartime Restrictions on Critical Materials.—The general subjects covered include, (1) Need for curing, (2) curing practice, (3) wartime conditions and (4) recommended specifications. The following types of curing are discussed, (a) cotton mats, (b) sprinkling, (c) ponding, (d) wet earth, sand or sawdust, (e) wet straw or hay, (f) waterproof paper, (g) non-bituminous seal coats, (h) bituminous seal coats, (i) sodium silicate, (j) calcium chloride—surface applications and (k) calcium chloride-admixture. The appendices contain the curing specifications for, (1) cotton mats, (2) calcium chloride, (3) sodium silicate, (4) waterproof paper and (5) liquid membrane seal coats. It also includes a Tentative Method of Test for Efficiency of Materials for Curing Concrete and a Suggested Surface Wear Test for Effect of Membrane Coatings on Quality of Concrete.

No. 2. Design of Highway Guards—With a view to the conservation of critical materials, at the same time realizing the necessity for the preservation of highway safety, this publication offers suggestions on the use of non-critical materials in highway guard construction.

The report includes descriptions and detail plans for the following types of guards, (1) Spring-Steel Bracket Timber, (2) Earth Mound, (3) Boulder, (4) Stone Masonry, (5) Timber and (6) Rustic. The wartime restrictions on timber use and a table showing the durability of different types of wood are also included.

No. 3. Design of Concrete Pavements Requiring a Minimum of Steel.—The need for conserving steel for war uses is universally recognized. Engineers are in agreement that during the emergency its use in construction should be limited to the minimum compatible with sound engineering procedure.

Steel is used in concrete pavement in the following forms: (1) Distributed steel in the form of bar mats or wire mesh; (2) Tie-bars across hinged longitudinal joints, including chairs or pins for their support; (3) Deformed metal dividing plate to form a type of longitudinal hinged joint; (4) Dowel bars or other load transfer devices across transverse expansion or contraction joints, including other steel used in connection with their installation.

This report discusses the functions of each of these uses of steel and the modifications in design and construction which will effect a reduction or elimination of steel. The bulletin also contains detailed plans of the various suggested war emergency designs.

No. 4. Maintenance Methods for Preventing and Correcting the Pumping Action of Concrete Pavement Slabs.—The recommendations contained in this bulletin are not restricted to wartime practice as they are applicable wherever the pumping action of concrete pavement slabs prevail. The general topics covered by the report are: (1) Definition of Pumping, (2) Causes of Pumping, (3) Preventive and Corrective Procedures, (4) Soils, and mixtures, including admixtures used by several States, and (5) Recom-

mended Field Procedure. The latter includes a discussion of (a) drilling, (b) filling void spaces and (c) equipment. The report also includes a list of references.

No. 5. Granular Stabilized Roads—The roads included in this classification are those which have been made usable in all weather by means of a mixture of soil and aggregate. The following factors are given consideration in the report: (1) Definition of Soil—Stabilization, (2) Structure of Granular Stabilized Roads, (3) Materials, (4) Tests—their significance and procedure, (5) Recommended Practice for Materials and Mixtures for Granular Stabilized Roads—includes grading specifications of materials for (a) Surface Course, (b) Base Course and (c) Sub-base, (6) Combining Materials for (a) plasticity index and (b) proper sieve analyses, (7) Compaction and Compaction Test, (8) Method of Determining Weight per Cubic Foot of Soil in Place, (9) Treatment with Deliquescent Materials and Sodium Chloride, (10) Road Thickness, (11) Construction Methods—including discussion on Road and Plant Mixing and (12) Maintenance, which includes index and (b) sieve analyses, (7) Compaction and Compaction Test, (8) Method of Determining Weight per Cubic Foot of Soil in Place, (9) Treatment with Deliquescent Materials and Sodium Chloride, (10) Road Thickness, (11) Construction Methods—including discussion on Road and Plant Mixing and (12) Maintenance, which includes recommendations for blading and the use of deliquescent and bituminous dust palliatives.

No. 6. Patching Concrete Pavements with Concrete—The general topics covered are: (1) Details of Design of the Patch, (2) Preparation of the Area, and (3) The Control of Replaced Concrete.

Under Design, the size and shape of the patches are classified into five types, (1) Full width patch—constructed a lane-at-a-time. (2) Half width patch, involving a single traffic lane. (3) Exterior edge patch. (4) Interior edge patch. (5) Plug patch. Figures are included which illustrate each type and give dimensions, locations and jointing arrangements.

The section on "Preparation of Area to be Patched," contains recommendations on (1) cutting old slab, (2) trimming edges, (3) cleaning edges, (4) underpinning old slab, and (5) subgrade preparation.

The materials, proportioning, mixing, placing, finishing and curing are discussed under the section on "Concrete."

The concluding part of the report includes the general practice in handling traffic, installing barricades and signs and cleaning up the site of the patching projects.

No. 7. Use of Soil-Cement Mixtures for Base Courses—The types of soil-cement construction described in this bulletin cover the incorporation of cement with subgrade soils, borrow soils, pit-run materials and combinations of these materials by mixed-in-place, traveling and stationary plant methods. The subjects in the report include: (1) Specifications for cement, water and soils, (2) Soil Surveys, Sampling and Analyses, (3) Cement Requirements, (4) Moisture Density Requirements, (5) Construction Equipment and Procedures, (6) Compaction and Finishing Operations, (7) Testing Compacted Materials, (8) Chemical Determination of the Cement Content of the Finished Mixtures, (9) Curing, (10) Type and Quantity of Bituminous Prime, (11) Construction Precautions, (12) Maintenance, (13) Patching, Salvaging and Reconstructing Low Cost Pavements with Soil Cement, and (14) Tentative Specifications for (a) Moisture-Density Relations of Soil-cement Mixtures, (b) Wetting-and-Drying Test of Compacted Soil-cement Mixtures, and (c) Freezing-and-Thawing Test of Compacted Soil-Cement Mixtures. The report also includes a list of references.